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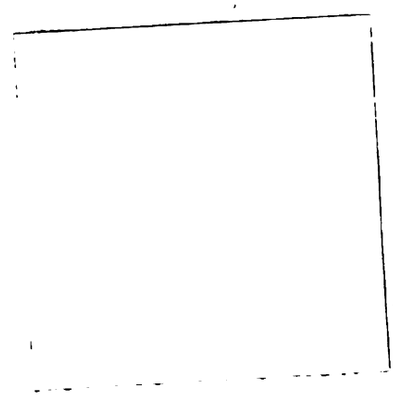

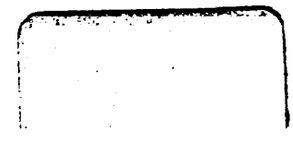

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

PROFESSIONAL PAPER 87

GEOLOGY AND ORE DEPOSITS

OF

COPPER MOUNTAIN AND KASAAN PENINSULA

ALASKA

BY

CHARLES WILL WRIGHT

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PREFACE.

By ALFRED H. BROOKS.

This report represents the results of an investigation made in conformity with a general plan to survey in detail the important mining districts of southeastern Alaska. This plan was begun by a detailed geologic survey of the Juneau district, completed in 1903,[1] and is being carried out as rapidly as the funds available will permit. The Copper Mountain and Kasaan Peninsula regions were surveyed in 1907 and 1908; the mineralized belt extending from Juneau to Berners Bay in 1910 and 1911.[2]

Meanwhile geologic reconnaissance surveys and preliminary investigations of mineral resources of all the mining districts of southeastern Alaska have been completed and their results published in several reports. There still remain a number of mining districts which should be surveyed in detail. Such work is very expensive because of the high cost of making the base maps in this region of dense vegetation and excessive rainfall. There is also need of more comprehensive study of the stratigraphy of southeastern Alaska. The mining districts which have been surveyed are regions of very complex structure and of igneous intrusion and metamorphism. Therefore these geologic surveys have been more useful in determining the occurrence of the ore deposits than in elucidating the general structure and stratigraphic sequence in the province. Plans are under consideration for a more exhaustive study of the stratigraphy of this province which it is hoped can be put into execution before long.

In 1909 Mr. Wright left the United States Geological Survey to take up private work in Sardinia, a fact that accounts for the long delay in the completion of this report, which has been prepared at such times as he could spare from his professional work. This delay is regrettable, but meanwhile the interests of the mining industry in this field have not been lost sight of, for the more important economic conclusions and the geologic maps were promptly prepared by Mr. Wright and published.[3] In justice to Mr. Wright it should be stated that he submitted this report in final form in September, 1912, but that a further delay in its publication was caused by the lack of funds for printing.

The descriptions of the developed ore bodies and mine workings here given must be regarded in the main as representing the information at hand up to the close of 1908. Since 1908 important discoveries and developments have been made on some of the properties here described, but these will only in part be referred to in this report. In the early part of 1914 some large operations on copper properties were begun in the Ketchikan district, but the collapse of the copper market led to the suspension of much of this work.

[1] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, 1906.

[2] Knopf, Adolph, Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 446, 1911; The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, 1912.

[3] Wright, C. W., Mining in southeastern Alaska: U. S. Geol. Survey Bull. 379, pp. 75–82 and Pls. II and III, 1909.

GEOLOGY AND ORE DEPOSITS OF COPPER MOUNTAIN AND KASAAN PENINSULA, ALASKA.

By CHARLES W. WRIGHT.

INTRODUCTION.

Location of areas described.—Kasaan Peninsula and Copper Mountain are now (1912) the two most important copper-bearing areas in southeastern Alaska. The first is a peninsula projecting into Clarence Strait from the east side of Prince of Wales Island; the second is a small area which encircles the base of Copper Mountain, on the west side of Prince of Wales Island, and which is readily accessible to ocean traffic by the upper part of Hetta Inlet. Both areas lie within the Ketchikan district or precinct. The town of Ketchikan, which is east of Clarence Strait, is the recording office of the district and an important commercial center.

Scope of report.—It is proposed to consider in detail the geology of Copper Mountain and Kasaan Peninsula. Special attention will be paid to the occurrence of contact ore deposits, which are well exemplified in this region. The mining development will be only briefly described, as it is not of permanent interest and is, moreover, fully treated in the Geological Survey's annual bulletins showing the progress of investigations of the mineral resources of Alaska. The detailed descriptions will be prefaced by a general account of the geology of the Ketchikan district, which is considered essential to an understanding of the details that follow.

Surveys and explorations.—Brief references to the occurrence of copper and other ores in the districts here under consideration appear in some of the earlier publications treating of southeastern Alaska. The first systematic study of this field was made in 1901 by Alfred H. Brooks. The resulting report [1] outlined the general geology of the Ketchikan district and briefly described some of the newly discovered copper deposits of Kasaan Peninsula and Copper Mountain. A more extensive geologic survey of this field was made by F. E. Wright and the writer in 1904 and 1905, and a report [2] on this work described at some length the geology and mineral resources of the Ketchikan district and included brief accounts of the ore deposits of Copper Mountain and Kasaan Peninsula.

All the above work was done without base maps, except the charts delineating the shore line. In 1907 and 1908 D. C. Witherspoon, J. W. Bagley, and R. H. Sargent made a detailed topographic survey of the Kasaan Peninsula.[3] Mr. Sargent made a similar survey of the Copper Mountain region in 1908.[4] These surveys were made on a scale of 1:45,000, and the results have been reduced for publication to a scale of 1:62,500. The contour interval on the map of Kasaan Peninsula is 50 feet, on the map of Copper Mountain 100 feet. The details of relief and drainage are shown with much precision. The mines and prospects are indicated by conventional symbols, as are also the wagon roads and trails.

Geologic study was begun in 1907 by the writer, assisted by Sidney Paige, when a part of the Kasaan Peninsula was covered. The mapping of this area was completed by the writer in

[1] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of the geology of southeastern Alaska: U. S. Geol. Survey Prof. Paper 1, 1902.

[2] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, 1908.

[3] Topography of Kasaan Peninsula, Prince of Wales Island, Alaska: U. S. Geol. Survey Alaska Sheet No. 540B, 1911.

[4] Copper Mountain and vicinity, Prince of Wales Island, Alaska: U. S. Geol. Survey Alaska Sheet No. 540A, 1911.

1908, as was also the geologic work in the Copper Mountain region. A total of six months in two seasons was spent on the work. During this time geologic surveys of about 86 square miles in Kasaan Peninsula and 45 square miles in the Copper Mountain region were made.

Although the preparation of the final report on this work has been long delayed, the geologic maps[1] and the results that bear on the occurrence of mineral deposits were published promptly and will be freely used in this report.

Geologic maps.—The general geologic map of the Ketchikan district (Pl. I) accompanying this report is only slightly modified from one previously published[2] which was prepared by F. E. Wright and the writer.

On the detailed geologic maps (Pl. V, p. 30, and Pl. XV, in pocket) the boundaries of the rock formations, where actually observed in the field, are indicated by solid lines; where only inferred, by broken lines. As outcrops are exceedingly scant in this moss-covered and timber-covered area, the distribution of the formations as indicated on the maps is in large measure only approximately accurate. If a contact between two formations is important in the search for ore bodies its exact position should be determined on the ground by stripping before extensive mining operations are begun.

This report includes a number of maps of mining properties and mine workings which have been furnished by the operators, the geology having been added by the writer.

Acknowledgments.—The field and office work for this report has been done under the direction of Alfred H. Brooks, to whom the writer is indebted for many valuable suggestions. To Fred. E. Wright and particularly to H. E. Merwin, of the Geophysical Laboratory of the Carnegie Institution of Washington, he is indebted for extensive petrographic studies. The stratigraphic and paleontologic studies of E. M. Kindle in this field have also been of great value. In the field work on Kasaan Peninsula in 1907 the writer was ably assisted by Sidney Paige, to whom much credit is due for geologic mapping. To the mine owners, operators, and prospectors of the districts, all of whom extended a hearty cooperation in the work and many personal courtesies, the writer is most grateful. Though impossible to mention all who aided in this investigation, the work was especially facilitated by U. S. Rush, of Kasaan; N. O. Lawton, of Hadley; W. B. Freeburn, of Mount Andrew; and Charles A. Sulzer, of Sulzer. Acknowledgment must also be made to the firm of Winter & Pond, of Juneau, for permission to use certain photographs here reproduced.

KETCHIKAN DISTRICT.

TOPOGRAPHY.

GENERAL FEATURES.

The Ketchikan district includes about 7,200 square miles in the southernmost part of southeastern Alaska. It embraces two distinct topographic provinces, the more rugged being the eastern or mainland belt and the adjacent islands, the largest of which is Revillagigedo, and the other, which has less strong relief, including Prince of Wales and some smaller islands. The coast line of the district is broken by innumerable straits, fiords, and minor indentations. The longest fiord, Portland Canal, which marks the boundary between Alaska and British Columbia, extends about 150 miles inland and is everywhere bounded by steep mountain slopes.

MAINLAND.

The general topographic aspect of the eastern or mainland portion of the Ketchikan district is similar to that of the other portions of the Coast Range province lying on the north and south. The mountains rise abruptly—at some places in sheer cliffs—from tidewater to elevations of 2,000 to 5,000 feet, and the peaks farther inland reach altitudes of 6,000 to 10,000 feet. These mountain masses are for the most part made up of immense batholiths of the granite of the

[1] Wright, C. W., and Paige, Sidney, Copper deposits on Kasaan Peninsula, Prince of Wales Island: U. S. Geol. Survey Bull. 345, pp. 98–115, 1908; also, Wright, C. W., Mining in southeastern Alaska: U. S. Geol. Survey Bull. 379, pp. 67–86, 1909. The geologic maps in this paper form Pl. II (p. 76) and Pl. III (p. 80).

[2] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, Pl. I.

Coast Range, and the land features are chiseled on a corresponding broad scale. Because of the mode of formation and physiographic development of these mountains there is in general a decided lack of bedrock control of the lines of drainage or erosion. Though profoundly dissected, the mountains show a notable tendency to uniformity in the elevation of their crest lines. The summits are generally broad and somewhat flat, and their backs are gently arched so that if the steep-sided valleys were filled to restore their original profiles, the region would present an undulating surface sloping gradually westward from the center of the range.

The form of the land indicates that the region has been intensely glaciated and but slightly modified by water erosion since the glacial epoch. At the time of its maximum extent the ice sheet covered the whole area except some isolated high peaks, which can now be identified by their sharp, serrated outlines—their lack of glacial rounding. Even during the present period of glacial drought a number of small ice fields still exist here in the Coast Range belt, lying above the snow line and sending small tongues down the valleys even to tidewater. The region contains abundant and striking features of glacial sculpture, such as U-shaped valleys, fiords, glacial erratics, cirques, hanging valleys, double-cliff slopes, truncated spurs, alignment of cliff bases, and glacial grooves and striæ. The notable absence of moraines in this area of extensive glaciation is due chiefly to the steepness of the slopes of the mountains and valleys. Many of the fiords are floored with sand and gravel moraines, and some of them are partly choked at their entrances by morainic material. Forelands occur here and there, but they are small, and the region includes no large areas of level land. The peninsulas and the adjacent islands are more or less separated from the mainland by deep, narrow fiords extending many miles inland and they contain mountains whose summits range in height from 2,000 to 4,000 feet above sea level.

The mainland belt is intricately dissected by narrow, steep-sided valleys heading in canyons, many of which are filled with snow, or in glacial cirques, a number of which contain small glaciers or patches of ice. The initial descent of these valleys is steep, the streams in places forming beautiful waterfalls of considerable volume. Farther down the slopes tributary creeks or rivers enter these streams from both sides, the valleys gradually widen, and the valley floors become covered with a gravel wash consisting largely of gravel, cobbles, and bowlders of granite. As the grade decreases the gravel beds become deeper and wider, and the stream flows around the flanks of precipitous mountain spurs and enters the sea at the head of some tidewater inlet. The tidal flats at these points are usually wide and are composed of deep fine sand and mud, the depth to bedrock being probably several hundred feet. They extend into the channels for a short distance beyond the low-tide line and there end abruptly. Depths of 50 to 100 fathoms are common in these inlets a short distance from the shore.

The seaward extension of many of these valleys is represented by tidewater channels or fiords. The largest of these in this region is Portland Canal, which penetrates the mainland for some 150 miles, with an easterly and then a northerly course. From its sides the mountains close at hand rise to elevations of 4,000 to 6,000 feet. Bear and Salmon rivers discharge into the head of this canal.

PRINCE OF WALES ISLAND.

There are no topographic maps of Prince of Wales Island, and little is known in detail of the courses of its valleys or of its mountain ranges. Its eastern shore line has been charted by the Coast and Geodetic Survey, but the mapping of the western coast is still incomplete.

Prince of Wales Island is 80 miles long and 30 miles wide, and is separated from the mainland by Clarence Strait, a deep channel 5 to 10 miles wide, trending about north and south. Its shore line is indented by numerous bays and inlets, which are characteristic of the entire coast. Portions of its west coast are directly exposed to the Pacific Ocean, but most of it is protected by small seaward islands, the largest of which is Dall Island. Viewed from the channels Prince of Wales Island presents a mountainous mass of very irregular outline. Its relief, however, is less rugged than that of the mainland or of some of the islands to the north, such as Baranof Island. A low pass across the island, 4 miles long and less than 150 feet high, connects the head of Cholmondeley Sound on the east coast with the head of Hetta Inlet on the west coast.

Another pass, 6 miles long, unites the south arm of Cholmondeley Sound with Klakas Inlet. The head of Twelvemile Arm also is connected with Big Harbor on the west coast by a portage several miles long. There are also probably other low gaps between the east and west coasts of the island. Numerous lakes occur on the island both in low-lying valleys and in basins lying at elevations of 1,000 to 2,000 feet. The mountain summits range in height from 2,000 to over 3,000 feet, one of the highest being Copper Mountain, 3,900 feet above sea level.

In general both the course of the valleys and the trend of the small mountain ranges of this island conform to the underlying rock structure, which has largely controlled the erosive processes. The intrusive masses and limestones usually persist above the general level and form the hills, ridges, and mountain peaks. The areas of shales, sandstones, and other less resistant rocks are marked by lowlands, deep valleys, and channels.

There are now no glaciers on Prince of Wales Island, but evidence of former glaciation is everywhere present. Basins scooped out by glacial action and now filled with lakes occur at elevations of a few hundred to 2,000 feet in the vicinity of Copper Mountain, and the surrounding mountains, composed essentially of granite, are well rounded and bear many large bowlders that are evidently erratics. In the Klawak Range, farther north, there are several clearly defined glacial cirques containing small lakes and surrounded by more or less jagged crest lines. Grooves observed at a few places on rocks exposed along the tidewater channels may also be attributed to glaciation.

The coast line of this and adjacent islands is broken by bays, coves, and channels. The charts of this area show numerous excellent harbors and many protected channels that favor navigation. One of the striking features is the shallowness of many of the bays and channels as compared with the depths noted in the fiords of the mainland belt. Again, the river deposits at the heads of bays have a gradual slope; they do not descend abruptly into deep water a short distance from the shore, as do the tidal flats along the mainland. These facts and the topographic observations tend to show the greater advance in topographic development of the seaward part of the region in contrast with that of the mainland.

CLIMATE.

The annual changes in climatic conditions in southeastern Alaska are not so varied as might be expected in a region lying between 55° and 60° north latitude. The effect of the warm waters of the northern Pacific is strongly felt and serves to moderate the climate. The region is characterized by mild winters and cool summers. The mean annual temperature is about 45° F. The mean temperature of the three summer months is about 55° F.; of the three winter months about 35° F. The precipitation is heavy and is greatest where high mountains abut on the sea. Nearly all the precipitation below an elevation of 500 feet is in the form of rain. Rainfall records in the Ketchikan district are scant, but indicate a total precipitation of about 98 inches at Shakan, near the north end of Prince of Wales Island, and of 148 inches at the town of Ketchikan. Most of the rain falls between the first of September and the last of January, though the amount varies greatly from year to year. The season of least rainfall is generally from April to July. The snowfall is heavy in the mountains, from 3 to 8 feet in depth, but near sea level not more than a few inches of snow falls at one time during an ordinary winter, and this soon disappears.

The prevailing winds come from the southwest and bear moisture from the sea, which condenses in the form of fog and rain about the mountain range. The abundant precipitation is trying to those who are accustomed to a more arid climate, but this rainfall, though a drawback to the prospector, does not interfere with mining development. It is an advantage, for it furnishes water power which can be utilized in mining operations.[1] Except at high altitudes snow does not interfere materially with transportation or mining.

[1] Hoyt, J. C., A water-power reconnaissance in southeastern Alaska: U. S. Geol. Survey Bull. 442, pp. 147–157, 1910.

VEGETATION.

The growth of timber and vegetation along the coast of southeastern Alaska is almost as dense as that of a tropical region. Its luxuriance is caused by the moist and temperate climate and the long summer days of this latitude. At elevations below 1,500 feet bushes, ferns, and tall grasses grow profusely, especially in the valleys and gulches. In places these form a dense and almost impassable undergrowth and are a great hindrance to the prospector. The timber is almost entirely of coniferous species, principally western hemlock and spruce, and is in general of an inferior grade, suitable only for rough work. The timber line ranges in elevation from 1,500 to 2,500 feet, but most of the large trees grow at low altitudes. The stands of commercial timber vary greatly, ranging from 30,000 to 80,000 feet (board measure) per acre. The average run of saw timber in southeastern Alaska, however, because of the scant growth in the swamps and on the higher slopes, is not more than 5,000 to 10,000 feet per acre.

The hemlock is used for piling, but most of the lumber cut in the local sawmills is spruce. The cedar is not sufficiently abundant to have much value. The entire Ketchikan district lies in the Tongass National Forest.

There are some good agricultural lands in the flats, but they are of small extent. Some of them have been successfully utilized for gardening, for which use the climate and soil are favorable.

COMMERCIAL CONDITIONS.

Ketchikan, the prosperous commercial center of the district, is on the west side of Revillagigedo Island, which lies close to the mainland about 15 miles east of Prince of Wales Island. It has a population of about 1,500 and is provided with all necessary municipal improvements. It is an important fishing center and has ample wharves, good hotels, banks, and stores. It is connected by cable with Seattle and with Alaska ports. Supplies can be purchased at little advance over Seattle prices. Coal is brought from Vancouver Island and retails at about $8 a ton (1908).

Communication is maintained between the mining camps and Ketchikan by steamships and launches. Ketchikan is 52 hours from Seattle by steamships following the inside passage, three to five entering the port every week from the States. Direct weekly steamship connection is also maintained with Vancouver, British Columbia. Prince Rupert, the western terminal of the Grand Trunk Pacific Railway, to be completed in 1915, is only 5 hours by steamer from Ketchikan.

The timber supply of the region is adequate for all mining purposes. The local sawmills furnish rough lumber, and good timber for piling is abundant. There are also some good water powers in the district, though they are but little developed. The irregular coast line affords many good harbors, which are free of ice throughout the year. As a general rule the country is one of strong relief, which is favorable to mining developments through adit tunnels and without hoisting.

The conditions in general in the district are exceptionally favorable to mining operations and, except for the irregularity of some of the ore bodies, are almost ideal for reducing operating costs to a minimum.

PRODUCTION OF COPPER.

The occurrence of copper deposits on Kasaan Peninsula was known even during the Russian occupation, but small heed has been paid to them except in very recent years. An attempt was made to establish a copper-mining industry near the present site of Kasaan in 1879–80, but it was abandoned after a few tons of ore had been mined and shipped. The copper now produced in the Ketchikan district is derived almost entirely from mines on Kasaan Peninsula and about Copper Mountain. The growth of the copper-mining industry in this field is shown in the following table:

Ore production from copper mines in the Ketchikan district, 1905–1911.

Year.	Ore mined.	Copper.		Gold.		Silver.		Average value of ore per ton.
		Amount.	Value.	Amount.	Value.	Amount.	Value.	
	Tons.	*Pounds.*		*Ounces.*		*Ounces.*		
1905	30,400	1,901,392	$295,616	1,178	$34,370	13,000	$7,867	$10.79
1906	85,139	4,350,571	838,660	3,031	62,851	27,152	18,102	10.81
1907	79,982	4,758,814	951,761	3,384	69,960	44,196	29,143	13.14
1908	43,215	3,260,399	430,372	2,213	46,310	24,648	13,063	11.10
1909	28,491	2,705,988	351,778	1,946	40,228	16,679	8,641	14.06
1910	27,425	2,254,487	286,320	1,503	31,081	14,598	7,884	11.86
1911	13,753	977,468	120,719	613	12,678	6,573	3,484	9.96
1912	13,494	1,234,888	203,756	1,080	22,335	10,035	6,171	17.21
1913	7,276	599,903	92,985	484	10,000	4,447	2,686	14.52
	329,175	22,043,900	3,571,967	15,432	329,813	161,328	97,041	12.15

The copper production of the district previous to 1905 is estimated at 1,600,000 pounds. At 12 cents a pound, the average price of copper for the period in which it was mined, the value of this output is $192,000. These amounts, added to those for 1905 to 1913, give a total copper production of 23,643,900 pounds and a total value of $3,763,967.

Practically the first large shipments of ore were made in the spring of 1905. The rise in the price of copper from an average of $0.156 a pound in 1905 to an average of $0.20 a pound in 1907 permitted the profitable extraction of copper ores of low grade averaging 59 pounds per ton, and with the improvements in methods of transportation and mining the production was much increased. In 1908 the average price of copper dropped to $0.132, and this led to the closing down of some of the principal producing mines. Of ten producing mines in 1907 only five were operated in 1908 and only three or four during the following years. From these the average copper content per ton of the ore shipped was about 90 pounds. In 1911 only three mines were producing, and the ore shipped yielded on an average 70 pounds of copper per ton.

GEOLOGY.

GENERAL FEATURES.

The geology of the Ketchikan district is but imperfectly known, for, except in the two areas to be described in detail below, observations have been confined almost entirely to the shore lines, and this limitation, together with the gaps in the information regarding continuity of formations and stratigraphic relations caused by the many broad waterways, has prevented the exact determination of either stratigraphic sequence or structure. Hence the sedimentary rocks of the region, which range in age from Silurian to Jurassic or Cretaceous, will be described in only a general way, but as the knowledge of the igneous rocks is more exact and comprehensive, these will be described in greater detail.

The geologic map (Pl. I) shows that the intrusives of the Coast Range occupy a larger area than any other of the rock units that have been discriminated. The main batholiths of these intrusives occupy the eastern part of the district and form a convenient starting point for a geologic description, though they by no means represent the oldest rocks of the district. Adjacent to these intrusives on the west and in part included within their area lies a series of crystalline schists which, though in places showing igneous phases, are for the most part sedimentary. The seaward and western boundaries of these schists are marked by a belt of argillites—either slates or phyllites—in part interbedded, in part succeeded by ancient lavas and tufts that are here grouped together as greenstones. Some semicrystalline limestone bands occur in this slate and greenstone series, and as Carboniferous fossils have been found in these limestones the entire sequence has heretofore been referred to the Carboniferous period. This determination of the age of the series accords with Spencer's [1] provisional determination of the age of similar rocks that apparently represent a northern extension of the same belt. Knopf's [2]

[1] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, p. 17, 1906.

[2] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 17–18, 1912.

recent studies north of Juneau have shown, however, that these rocks are in part, at least, of Jurassic or Lower Cretaceous age. This series of slates, phyllites, schists, and greenstones may therefore be Mesozoic, though it may include some infolded Carboniferous limestones. On the map the sedimentary rocks adjacent to the Coast Range are not differentiated from the sedimentary rocks that lie farther west, most of which are older than those near the Coast Range.

But few correlations have been made between the rocks of Prince of Wales and adjacent islands and those of the mainland belt described above. Igneous rocks like those found in the Coast Range occur as intrusives in this western province. Some of the sedimentary rocks here are also lithologically the same as some of those found farther east, and the likeness suggests certain correlations which can not yet be definitely established. The sedimentary rocks of Prince of Wales Island include slates, quartzites, arkoses, and conglomerates, and locally a large amount of limestone. The fossils found in these rocks indicate the presence of strata ranging in age from Silurian to Carboniferous. The rocks of the island include also a series of volcanic deposits and another of graywackes and conglomerates, which on stratigraphic grounds have been assigned to the Mesozoic. The Paleozoic formations have not been differentiated on the geologic map (Pl. I), which therefore indicates a sameness in the geology of Prince of Wales Island that is by no means in accord with the facts. The continuity along strike lines that is characteristic of the mainland does not prevail on Prince of Wales Island, where the rocks show close folding, which, with the presence of many large stocks of igneous rocks, has given great variety to the geology. The Tertiary period is represented in the district by one small area of conglomerate, sandstone, and shale; the Quaternary by many widely distributed basaltic lava flows, though none of any great areal extent.

Of the igneous rocks the intrusives of the Coast Range, made up of granite, diorite, granodiorite, and peridotite, are most abundant and most widely distributed. These are believed to be of Mesozoic age. Dikes of diabase, porphyrite, and felsite are widely distributed and are probably later intrusives.

SEDIMENTARY ROCKS.

PALEOZOIC STRATA.

Little or nothing is known of the oldest rock formations in the district, but it is doubtful whether they include pre-Paleozoic strata. The crystalline schists and gneissoid rocks, which form a wide band adjacent to the Coast Range and resemble the ancient metamorphic clastics of other regions, are mostly of late Paleozoic and early Mesozoic age, and their present crystalline condition is attributed to metamorphism caused in part by the intrusives of the Coast Range.

The sedimentary record begins with the Silurian, which is represented by fossiliferous limestones. These limestones include thick strata of banded graywacke, and the limestone and graywacke together form a belt that is exposed at points on the west coast of Prince of Wales Island and on Kasaan Peninsula. The banded graywackes are nearly everywhere extremely fine-grained or aphanitic, indurated, clastic rocks, gray to green in color, very brittle, with little or no cleavage. They include both sedimentary strata and indurated beds of tuff with mixed sedimentary material. Weathering usually produces a brown surface by the oxidation of pyrite and other ferruginous particles. The total thickness of the beds can not be estimated because of complicated folding, though it must amount to many thousand feet.

At the base of the Devonian lie thick beds of conglomerate containing pebbles and cobbles derived from the older Silurian beds, and indicating that an unconformity occurs between the Silurian and Devonian strata, though the rocks of these two periods were not observed in contact.

At many places along the northwest shore of Prince of Wales Island and on the smaller islands adjacent to Davidson Inlet a thick series of limestones overlies these beds of conglomerate, and together the two series represent the lowest horizon of the Devonian system. The con-

glomerates consist essentially of cobbles of banded quartzite and some fragments of limestone and schist. Toward the limestone beds they grade into sandstone and slaty limestone. They are conformably overlain by the limestones. Narrow beds of the sandstone are also interstratified with the beds of limestone. The limestones are semicrystalline and gray to blue in color, and not many of the fossils in them are identifiable. At several points, however, imperfect fossils, which have been referred to the Devonian, were gathered, the largest collection having been obtained on the east shore of Haceta Island, from beds directly overlying the conglomerates.

The total thickness of the conglomerate beds is estimated at 1,200 feet and that of the overlying limestone beds at 1,800 feet. At this locality the strata are broadly folded and the rocks are considerably metamorphosed.

A somewhat higher horizon of the Devonian is represented by the limestone beds on Long Island, in Kasaan Bay, on the east side of Prince of Wales Island. At this locality both Lower and Middle Devonian faunas have been recognized, though the limestone strata containing them are apparently conformable.

The stratigraphic relations of the limestones of Long Island to the beds on the adjacent shore of Kasaan Bay can not be definitely determined because of their topographic isolation.

The Middle Devonian horizon occurs again about 20 miles south of Long Island, at the head of Clover Bay, where there is a small area of schistose argillites and black limestone almost completely surrounded by an intrusive mass of diorite. These beds are highly tilted and have a general easterly strike.

At Vallenar Bay, on the north end of Gravina Island, beds of shaly limestone, argillaceous schist, and schistose conglomerate containing a Middle Devonian fauna occupy the crest of an anticline. These beds underlie the slates and greenstones which border the east and west shores of the island. The Devonian beds at this locality and those on Long Island were included under the name Vallenar series by Brooks in his report on the Ketchikan district.[1]

Limestone beds containing an Upper Devonian fauna and overlying with apparent conformity banded argillaceous beds, similar to those of Middle Devonian age exposed at Clover Bay, occur on San Juan Bautista Island and in Klawak Inlet, on the west coast of Prince of Wales Island.

The distinctions between the three divisions of the Devonian—the Upper, Middle, and Lower—in most places are not clearly defined paleontologically, and at no locality was a complete section of these horizons obtained.

The stratigraphic relations between the early Carboniferous and the late Devonian formations are not definitely known, and in no place were the formations observed together. The early Carboniferous is represented by fossil-bearing limestones on an islet at the entrance to Soda Springs Bay, on the west coast of Prince of Wales Island. The limestone beds strike north and are steeply tilted toward the east. They overlie with apparent unconformity conglomerates and sandstones that resemble those of early Devonian age. On Prince of Wales Island opposite this islet there are slates and chlorite schists which resemble those probably belonging to the slate and greenstone series of Copper Mountain.

Fossils were found in beds of calcareous shale that outcrop on the south end of Gravina Island, 3 miles north of Dall Head. These fossils were fragmentary and could not be definitely determined, but are provisionally referred to the early Carboniferous. They may, however, represent a Triassic horizon.

Few data exist concerning the interval between the early and late Carboniferous faunas, as the rocks containing the two faunas are nowhere present at the same locality and no fauna representing the intervening epoch has been found. The upper Carboniferous, which probably includes the most extensively developed formations, is represented by fossiliferous limestone beds at George Inlet, within the mainland belt, and at several points on the islands. In the mainland belt the limestones are included in a succession of argillites and crystalline schists, which are closely folded and highly metamorphosed and form a band about 10 miles wide

[1] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: U. S. Geol. Survey Prof. Paper 1, pp. 42–43, 1902.

adjacent to the intrusives of the Coast Range. These metamorphic strata, called by Brooks [1] the Ketchikan series in this province, probably include several formations, which, however, have not been defined because of the complexity of their structure and the extent of their metamorphism. They probably include formations as old as the Carboniferous and as young as the Jurassic (see p. 16), but the subdivisions have not yet been differentiated. Similar rocks are widely distributed, not only on the mainland and adjacent islands but on the west coast of Prince of Wales Island.

The most recent of these metamorphic rocks are the greenstone lava and tuff beds interstratified with beds of black slate. The structural relations of these beds to the older and younger rocks indicate that they are upper Carboniferous or Mesozoic, as they overlie the limestones (Carboniferous) and schists with apparent conformity. Similar rocks in the Juneau district were described by Spencer [2] as the "slate-greenstone band." Knopf's recent work has shown that these sediments in the Juneau district are probably of Jurassic age and has correlated them with the Berners formation, made up of slates, graywacke, and some greenstones.[3]

The greenstone and slate series of the Ketchikan district trend in many places parallel to the older limestones and schists, although they exhibit many local variations in strike and dip. Their total thickness is estimated to be over 4,000 feet. They occur principally along the outer border of the mainland belt in Tongass Narrows and on Cleveland Peninsula, but they also form a smaller belt along the west coast of Prince of Wales Island.

As a whole, the greenstone members of this slate and greenstone series predominate over the slate or the sedimentary beds, but the relative proportion varies from place to place, presumably because of inequality in the distribution of the lava flows and tuffs. The igneous and sedimentary material in these beds is intimately associated in varying amounts and grades from altered andesitic lavas and tuffs to purely sedimentary beds.

MESOZOIC STRATA.

The formations in the Ketchikan district that have been referred to the Mesozoic era contain no fossils, and the determination of their age is therefore based entirely on their structural and petrographic features. The possible Mesozoic age of the slate and greenstone series has just been indicated.

So far as known, the intrusives of the Coast Range, which occupy about half the land area of southeastern Alaska, invaded the bedded formations early in the Mesozoic era. These intrusives are discussed under the heading "Igneous rocks" (p. 20).

At the south end of Prince of Wales Island there is a series of andesitic flows, conglomerates, and tuffs, which grade into a series of graywackes or indurated sandstones, including some beds of slate. These rocks have been considered Mesozoic because of their structural and petrographic relations to the older rocks. In this series basaltic and andesitic flows are intercalated with tuffaceous beds, and both flows and tuffs alternate with the sedimentary slates, graywackes, and conglomerates. The rocks of the series are readily distinguished from the greenstones by the wide difference in the composition and texture of the interstratified beds and by their predominant reddish color. A fine, compact green tuff is usually overlain by an andesitic lava containing numerous large plagioclase phenocrysts, which is in turn overlain by a basaltic lava or a red lava conglomerate. The greenstone beds, on the other hand, vary little in composition and, where massive, augite crystals form the phenocrysts.

On the south end of Prince of Wales Island the andesitic flows and conglomerates overlie at several points the eroded surfaces of granitic intrusive masses, and numerous dikes of the andesite intrude these older granites. Pebbles and fragmentary masses of the granite were observed in the tuffaceous conglomerates, showing clearly that the andesites are younger than these masses of granite rock. The granites at this point were more altered and contained more shearing planes than are generally found in the intrusives of the Coast Range, and they may

[1] Brooks, A. H., op. cit., pp. 44–45.
[2] Spencer, A. C., op. cit., pp. 16–17.
[3] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 13–14, 1912.

represent a batholith intruded before or during the earliest stages of the granitic invasion of that range. The graywackes overlying the andesites are compact and indurated but show no schistosity. Pebbles of granodiorite, quartz, andesite, and graywacke are plentiful in the conglomerates. These beds as a whole, though tilted at steep angles and folded, have not suffered the intricate folding and metamorphism seen in the older rock beds, including those of the Sitka district. No fossils were found in these beds, but the facts above stated indicate that they occupy a position in the stratigraphic column between the Triassic and the Upper Cretaceous. It is possible that their horizon may be the same as that of the slate and greenstone found adjacent to the Coast Range batholith. (See p. 16.)

TERTIARY STRATA.

Tertiary beds are widely distributed along the Pacific seaboard of Alaska, though their total areal extent is comparatively small. In the Ketchikan district they are found only on Prince of Wales Island, where they occupy a small basin at Coal Bay, a southern arm of Kasaan Bay.

The Tertiary rocks comprise conglomerates, sandstones, and impure lignitic coal seams. They are soft, friable, and unmetamorphosed. There are very few exposures of these rocks, but judging from the better-developed Tertiary beds to the north they are probably but little disturbed.

RECENT DEPOSITS.

The few Recent deposits in the districts under discussion consist of stream gravels covering narrow valley bottoms and somewhat more extensive deposits at mouths of deltas. Some stream terraces noted on Kasaan Peninsula are probably underlain by gravels. Most of the beaches are rocky, consisting generally of almost shear cliffs, but locally some small sand and gravel beaches have been developed. In places in tidal flats there are also some more extensive deposits of fine alluvium. Glacial deposits of various types also occur in the Ketchikan district. None of these Recent deposits is indicated on the accompanying geologic maps.

IGNEOUS ROCKS.

CLASSES DISCRIMINATED.

The igneous rocks include (1) the intrusive masses, such as the dioritic and granitic batholiths, gabbros, and peridotites which invade the sedimentary rock beds; and (2) the extrusives, or those which represent surface lava flows, such as the greenstones, andesites, and basalts. The most abundant and important of the igneous rocks are the granitic intrusives of the Coast Range, which occupy about one-half of the aggregate land area of the district.

INTRUSIVES OF THE COAST RANGE.

GENERAL FEATURES.

The Coast Range massif as it has been defined by Dawson is not of the same composition throughout, but is composed of different kinds of igneous rocks, ranging from granite to diorite. The most noteworthy feature of the entire Coast Range mass of intrusives is their general uniformity in texture and their continuity. The variations across the range are apparently not so gradual as those along its trend. The Coast Range massif consists of many separate interlocking batholiths, or batholiths within batholiths, intruded at successive epochs but during the same general period of irruption.

The petrographic field term "granite," which has been generally used to designate these intrusives, applies to only a small part of the rocks, the prevalent type being a quartz hornblende diorite, though gradations to granodiorite, diorite, and gabbro, with hornblende and biotite as colored constituents and titanite as a frequent visible accessory, are common. As a general rule hornblende appears to be more abundant near the coast, while biotite predominates near the inland border of the Coast Range batholiths.

Although the composition of the batholiths varies considerably from point to point, it is desirable to ascertain the approximate average composition of the entire mass. To this end seven typical specimens were selected from different parts of the range. These specimens were chosen with special regard to their abundance and general distribution throughout the area, abnormal and rare types being disregarded altogether. Each of these specimens was studied in detail under the microscope, and a careful estimate of the relative quantity of each mineral in the rock was made from the thin sections by the Rosiwal method. Although the values thus obtained are only approximate, they represent roughly the general mineral content of the batholiths.

The following average mineral composition was thus obtained:

Average mineral composition of the intrusives of the Coast Range.

Quartz	19.4
Orthoclase	6.6
Andesine ($Ab_{56}An_{44}$)	47.4
Hornblende	7.6
Biotite	11.6
Apatite	.6
Magnetite	.9
Pyrite	.1
Titanite	1.3
Epidote	3.5
Chlorite	.1
Calcite	.1
Kaolin and muscovite	.8
	100.0

The average specific gravity, 2.77, was determined by weighing the hand specimens in air and then in water.

From these data the average chemical composition was calculated by assuming for the hornblende and biotite the compositions of like minerals from a similar rock from Butte, Mont.

Average chemical composition, norm, and classification of the intrusives of the Coast Range.

Average chemical composition.			Norm.			Classification.
Constituent.	Per cent.	Molecular ratio.				
SiO_2	61.0	1.017	Q	16.14	16.14	Class, $\frac{Sal}{Fem}=4.78$
TiO_2	1.0	.013	Or	13.32	84.26	
Al_2O_3	17.5	.171	Ab	27.78	68.12	Order, $\frac{F}{Q}=4.22$
Fe_2O_3	1.6	.010	An	27.02		
FeO	2.7	.038	Di	4.81	10.56	Rang, $\frac{K_2O'+Na_2O'}{CaO'}=0.82$
MnO	.1	.001	Hy	5.75		
MgO	2.4	.060	Mt	2.32	4.29 15.52	
CaO	6.9	.123	Il	1.97		Subrang, $\frac{K_2O'}{Na_2O'}=0.45$
Na_2O	3.3	.053	Ap	.67	.67	
K_2O	2.3	.024				
H_2O	.9	.050				
P_2O_5	.3	.002				
	100.0					

Its chemical and mineral composition places this rock in the family of quartz diorites, of the type tonalite, according to the usual classification. In the quantitative classification of Cross, Iddings, Pirsson, and Washington the rock is dosalic, dosalone, quardofelic, alkalicalcic, and dosodic, and belongs in Class II, order 4 (austrare), rang 3 (tonalase), and subrang 4 (tonalose). In short, it is tonalose of the ordinary type.

The amount of titanite is unusually large, as it is in many of the intrusives of the Coast Range. The hornblende occurs usually in dark prismatic crystals, noticeable for excellent prismatic cleavage and lack of terminal faces. Many biotite flakes are hexagonal and deep brown in transmitted light. A few crystals of apatite are visible to the unaided eye, but this

mineral occurs generally in fine hexagonal microscopic crystals. Pale-green veinlets of secondary epidote, which follow fracture planes in the granodiorite, are not rare.

These even-grained rocks generally have the normal, sharply defined, granitoid texture, but include also gradations to holocrystalline porphyritic phases, due to the superior development of the feldspars. Gneissic structure is common near the western margin of the Coast Range belt. In some places gneissic structure has been so far developed in the granite and the neighboring invaded sediments have been so thoroughly converted to gneiss that it is difficult to define the precise limits of the original intrusive granite.

CONTACT FEATURES.

The granite near the contact contains abundant inclusions of the intruded schist. These inclusions become more and more coarsely crystalline away from the contact, until finally they resemble basic or acidic differentiation products and are gradually lost to sight. Pegmatite and aplite dikes form an intricate network and mesh of white strands along the outer portions of the granodiorite massifs and in the adjacent schists, but are practically absent in the central parts of the batholiths. Several systems of such dikes were observed. The oldest set occurs as thin narrow bands following master joint planes and standing out as ribs above the surface of the more easily weathered granite; a second set is wider and usually perpendicular to the first; and a third and still later set, which is distinctly irregular, apparently fills the largest fracture cracks. This condition suggests that during the last period of magmatic activity the rock masses underwent considerable movement and fracturing and were brought nearer the surface. That still later differential movement has taken place is evident from the minor faulting of the pegmatite dikes themselves. At a distance this schist complex, with its innumerable pegmatitic dikes, resembles a breccia, the white pegmatites acting as interstitial cement for the dark angular fragments and blocks of schists. The occurrence of these innumerable pegmatites in the schists along the margin of the Coast Range batholiths is a significant indication of the immense quantities of pneumatolytic solutions given off by the invading crystallizing magmas. However, in this region of most intense development of pegmatites, the amount of ore deposition was slight and no large ore bodies have been discovered.

Farther away from the granitic intrusion magmatic solutions given off by these igneous masses penetrated the schists and encountered conditions more favorable to the precipitation of the metallic sulphides carried in solution and deposited them. As a result the argillites and slates a few miles west of the contact, as on Cleveland Peninsula and Revillagigedo Island, are very heavily impregnated with sulphides, and in certain places the precious metals have been in quantities sufficient to form valuable deposits.

The sedimentary rocks flanking the Coast Range batholiths in this region are folded closely near the contact and more openly at a distance so that, though their general trend is parallel to the range, their dip is extremely variable, ranging from northeasterly to southwesterly at all angles. Within the granite area itself are occasional belts of included sedimentary rocks in a highly metamorphosed condition. They vary from argillites to mica, hornblende, and calcareous schists of various types, even marble, and occur in long bands, intensely folded. They still preserve in general their northwest trend, parallel to the course of the range, and their steep northeasterly dip, and they are walled in by great mountain masses of intrusive granite. Most of the included belts of schist in the Coast Range are not wide, and more appear near the mountain tops than at sea level. They can be traced up the exposed cliffs and bare mountain sides for 4,000 to 6,000 feet. They are in many places intensely mineralized with sulphides, especially pyrite, and near the mountain crests show abundant evidence of contact metamorphism and the formation of garnetiferous rocks.

A comparison of the metamorphic effects of the intrusive granite along its western and eastern flanks in the latitude of the Ketchikan district shows decided differences. On the coastal side the metamorphism near the contact is usually of the deep-seated type; gneisses and schists predominate and are cut by innumerable pegmatite dikes ramifying from the granite. Mineralization by sulphides is not pronounced near the contact. Farther west, at some distance from

the contact, evidences of contact metamorphism increase and the degree of mineralization also increases, valuable ore bodies having been discovered within this zone in the Ketchikan district. Along the eastern border of the granite, on the other hand, the metamorphism is of the contact type, and argillites and slates predominate and are in many places indurated and heavily impregnated with sulphides. Well-defined ore bodies have been found near the granite contact. The geologic interpretation of these data indicates clearly that the rocks east of the massifs were less deeply buried at the time of intrusion than those on the coastal side. In other words, the inland rocks were then above the zone of deep-seated metamorphism or rock flowage and were therefore profoundly affected by the invading intrusives and accompanying pneumatolytic solutions. Furthermore, the mineral-bearing solutions emanating from the granite encountered new conditions of temperature and pressure on entering the adjacent sedimentary rocks and deposited, as supersaturated solutions in their new environment, a portion of their dissolved contents, especially the metallic sulphides and silicates.

In this large belt the phenomena of contact metamorphism are not so pronounced and concentrated as in the contact aureole of a small intrusive boss, such as at Copper Mountain. They are equally varied, though more extensive and on a larger scale. It has frequently been observed that in a small contact aureole different contact minerals occur at different distances from the intrusive mass, and that under similar conditions an evident relation exists between a given contact mineral and its distance from the invading rocks; and in a general way this law apparently holds true for this eastern contact zone of mineralized sedimentary rocks.

As further evidence of the important part played by the intrusives of the Coast Range, it may be noted that the ore deposits are apparently all later than these intrusives; that occasionally the pegmatite dikes in this area pass gradually into quartz veins, and that the evidences of contact metamorphism and the development of contact minerals such as staurolite, garnet, and andalusite are not rare in the heavily mineralized rock belts. Nearer the Coast Range the rocks now exposed were at the time of intrusion deeply buried and therefore extremely hot and under considerable pressure. The solutions, escaping from the granite and entering this complex, encountered conditions not greatly unlike those within the crystallizing granite itself, and sulphide deposition was slight. On reaching the zone of less pressure and colder rock formations, however, the ascending solutions met conditions favorable to the precipitation of sulphides and minerals closely allied to those of ordinary contact metamorphism, where heat and magmatic solutions are the prime agents of metamorphism.

OTHER INTRUSIVES.

Dikes of diabase, andesite, porphyry, and felsite are common throughout the region and cut all the older rock strata. Some of these have been indicated on the geologic map. The importance of these rocks, however, is relatively small when compared with the intrusives of the Coast Range and their accompanying dike rocks. For the most part these dikes may be considered as intrusive forms of the greenstones, andesites, and basaltic lavas. Diabase, the most widely distributed dike rock in the region, cuts the ore bodies in many places. It usually has a fine-grained ophitic texture, is dark green, and consists essentially of altered plagioclase feldspar, together with basaltic hornblende largely altered to uralite. Both magnetite and pyrite are generally present in disseminated grains. The porphyries, which may be regarded as the dike rocks of the andesitic lavas, are characterized by their porphyritic texture, by their light-green color, and by large phenocrysts of plagioclase feldspar contained in a finely crystalline groundmass. These dikes are numerous along the shore exposures, where they cut the Paleozoic strata and the granitic intrusives. Narrow dikes of basalt were observed on Kasaan Peninsula and at other localities. They are usually black, finely crystalline, and porphyritic, and vary widely in composition. The basalts are the most recent intrusive rocks.

EXTRUSIVES.

The greenstone extrusives mentioned in the foregoing pages are represented essentially by tuffaceous strata and lava flows, which have been generally metamorphosed and rendered

schistose, their original mineral constituents having been replaced to large extent by secondary products. Because of this alteration the former character of the rock has in most places been obliterated, but elsewhere their texture and mineral content mark them as igneous rocks. The interstratification and the intermingling of the igneous material with the black slates indicate that most of the igneous material, composed of tuffs and some agglomerates, resulted from volcanic outbursts. Lava flows also occur, but are less frequent. They are somewhat metamorphosed, have a greenish cast, and range in composition from altered andesites and andesitic tuffs to basalts and altered gabbros.

In their most altered form the greenstone schists are fine grained and are composed largely of chlorite, calcite, and secondary hornblende, which give the rocks a dark-green color. These schists, where permeated by mineral-bearing waters, contain considerable amounts of pyrite, and in several places have been bleached to a light yellow, as on Gravina Island and Cleveland Peninsula.

As is shown on the general geologic map, the greenstones are distributed along the mainland belt including Gravina Island, Cleveland Peninsula, and Duncan Canal and are also well developed along the shores of Hetta Inlet and on Shukwan Island. The greenstones are irregularly involved with the slates, limestones, quartzites, and schists, having been folded and compressed with them, and are considered to be essentially of the same age.

The extrusive rocks provisionally referred to the Jurassic or the Cretaceous are made up of lavas and tuffs like those of the upper Carboniferous. These extrusives include altered andesites, hornblendic porphyries, quartzose porphyries, and basalt tuffs. With these extrusives are included fragmental or clastic rocks composed of volcanic tuffs, sandstones, and conglomerates. As a whole the lavas are less prominent than the clastic rocks. They are intercalated with the sedimentary slates and sandstones or graywackes. The original character and manner of deposition of extrusives must have been very similar to that of the older greenstones. They are, however, readily distinguished from the greenstones by differences in composition and texture and by their dominant reddish color, and also by a difference in the amount of apparent metamorphism of the extrusives. They have not been changed to chlorite or talcose schists and do not show the degree of alteration that is characteristic of the older greenstones. As indicated on the accompanying map, the andesites occupy irregular areas on the south end and along the west coast of Prince of Wales Island but are not known to occur in other portions of the Ketchikan district.

Basaltic lavas of postglacial age occupy small areas at many points along the mainland and on Revillagigedo Island. They lie in nearly horizontal beds on the upturned schists and granitic rocks. The massive lava dominates, but narrow beds of tuffaceous material or ash were also observed. These flows correspond to the lavas on Kruzof Island in the Sitka district to the northwest.

STRUCTURE.

A consideration of the entire coastal province of southeastern Alaska brings out several important features which throw light on the dynamic history of the region. In the Ketchikan district alone these features are not very clearly marked. Prior to the development of the main northwest-trending structural lines, which at present dominate this coastal province and are most pronounced adjacent to the wide areas of intrusive rocks, the prevalent structure was made up of northeastward-trending folds. These folds still form a minor system, prominent on the west coast of Prince of Wales Island. The later and more intense folding of the beds, on a broader scale, which forms the major system and trends northwestward, has in general obliterated this minor system. Nearer the intrusive belts the larger system gradually prevails, and the minor folds as a whole are combined in the broader anticlines and synclines of the major northwest-trending folds. Complex minor folding and fracturing is thus produced in the beds. The fact that beds of upper Carboniferous age have this northeasterly folding indicates that this was the dominant bedrock structure at the close of the Paleozoic era. Whether the younger system of folding was produced just before the intrusion of the granite of the Coast Range or at the time of its invasion has not been definitely established, though, as suggested

by Spencer,[1] it was probably before the invasion of these igneous rocks, as the planes of contact, with few exceptions, follow the planes of bedding; to present this structure the strata must have been highly tilted and must have occupied a position similar to that which they now have. Along the mainland, across a width of from 5 to 10 miles, the uniformity of the strike and dip of the stratified rocks adjacent to the Coast Range batholiths indicates a monoclinal structure. Such interpretation, however, would necessitate a still greater thickness of the rock beds at the time of their deposition, as in their present condition they are greatly compressed and metamorphosed. From the evidence of broad folding of the beds it is reasonable to assume that this rock belt has the structure of a closely folded and compressed synclinorium, in which the tops of the anticlines have been removed, leaving little or no definite proof of their existence.

After this great period of mountain building, which is believed to have occurred about the close of Paleozoic or in early Mesozoic time, further important orogenic movements of the earth's crust took place and are clearly shown in the Mesozoic beds on Prince of Wales Island. In certain localities these beds overlie the granite intrusives and have assumed a steeply tilted position, with a northwesterly strike, and are considerably metamorphosed, but at other places they are only slightly folded and show no persistent direction of strike or dip and but little metamorphism. The forces producing this later structure affected the older Paleozoic strata largely by faulting, fissuring, and tilting, and not by intensé folding. The structural characteristics in the more recent rock formations indicate tilting and faulting, and there is little or no evidence of folding or metamorphic action. The effects appear to be confined largely to the basins or local areas occupied by these rocks, and in the older beds faults and fissures were probably produced along which the basaltic lavas subsequently found egress.

In addition to the preceding description of the different periods of dynamic revolution, the structurally significant faulting which accompanied these orogenic movements deserves special consideration. Evidence of these faults is shown by the local discontinuity of the strata. These faults, which are possibly numerous, are parallel to the bedding, and are therefore difficult to decipher, because of the extreme metamorphism of most of the rocks.

OUTLINE OF GEOLOGIC HISTORY.

The sedimentary record in this province begins with the deposition of a series of fragmental rocks, now represented by banded quartzite, sandstone, a few beds of conglomerate, and some tuffaceous material. These clastic rocks grade upward into calcareous beds and into limestone containing a Silurian fauna. Though the age of the earliest sediments has not been determined they are believed to be mostly Silurian, as they are succeeded with apparent conformity by limestones of that age. However, since their thickness is estimated at 10,000 feet or more, it is possible that their deposition began in an earlier period. At all events the record shows that sedimentation was probably continuous during early Silurian time, when clastic rocks were deposited to a great thickness, and that there was then a gradual deepening of the sea, and several thousand feet of limestone strata were laid down. The deposition of this Silurian limestone was possibly followed by a period of earth movement, during which the rocks were indurated and more or less folded, but of this fact there is no definite proof.

The oldest representative of the Devonian system is a succession of conglomerate and sandstone beds, composed largely of igneous material, which in most places appear to be less altered than the Silurian limestones and underlying clastic rocks. The pebbles of the conglomerate are embedded in a tuffaceous matrix and were derived chiefly from the older banded quartzite and limestone strata. This series, which is estimated to be 1,200 feet thick, grades upward with apparent conformity into the Lower Devonian limestones. These calcareous beds are nearly 2,000 feet thick and their period of deposition probably extended well up into Middle Devonian time. In other parts of the region the Middle Devonian is represented by argillaceous schists and slaty limestones, but the relations between these and the early Devonian limestones are not known. After deposition of the slaty limestones and argillites and apparently conformable with them a limestone of considerable thickness was laid down in Upper Devonian

[1] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, p. 14, 1906.

time. This later limestone, though highly crystalline and in places folded, does not generally show the intensity of dynamic action which characterizes the older limestones.

The Carboniferous period seems to have been begun by the deposition of gray limestone beds 1,500 feet or more in thickness, and, though the relations between these beds and the underlying Devonian strata have not been clearly determined, it is probable that a deep sea covered this region from late Devonian to early Carboniferous time. Along the mainland the corresponding limestone beds are infolded with argillites and crystalline schists and are highly metamorphosed. These argillites are, in part at least, Mesozoic. A long period of volcanic activity followed. The beds of lava and ash ejected from the volcanic vents were contemporaneous with the slate beds, and because of their intimate association with the sediments the volcanics are regarded as submarine extrusives. They are now represented by the altered massive greenstones and greenstone schists, which are widely exposed throughout the region and, together with the interstratified slate beds, have a thickness estimated at about 4,000 feet.

The sequence of geologic events during the Mesozoic era is not clearly defined because of the lack of paleontologic and structural evidence and because of the great orogenic changes which took place during this era. During early Mesozoic time the bedded rocks suffered intense metamorphism and recrystallization, resulting in the conversion of the sedimentary strata to schists and slates and in the alterations of the volcanic rocks to amphibole schists and chloritic greenstones. At the same time the beds were highly tilted and intricately folded, the direction of the axes of folding being generally southeast. These changes are exemplified more clearly in the beds flanking the Coast Range than in the sedimentary rocks composing the outer islands. Early Mesozoic slates have been recognized in the Berners Bay district, and, as suggested by Brooks,[1] probably Triassic beds are infolded with these older metamorphosed sediments in the Ketchikan district. The large development of the Triassic deposits to the south in British Columbia points to the same conclusion.

The most important event in this district during Mesozoic time was the intrusion of the great batholiths of the Coast Range. A study of the section across the axial mass of the Coast Range itself shows that the mass is not a simple batholith but is made up of successive intrusions along the same general line of weakness in the earth's crust. On the outlying islands granitic masses, which are much altered and contain many shearing planes, are invaded by granitic intrusives only slightly altered, which in turn are intruded by pegmatitic dikes and masses. Between these successive intrusions considerable time probably elapsed. The main folding and tilting of the bedded rocks referred to above probably preceded the actual invasion of the granodioritic rocks, as suggested by Spencer,[2] a suggestion based on the fact that their lines of intrusion are in a broad way parallel to the bedding planes and schistosity of these older rocks, also on the fact that a few inclusions of schist fragments occur within the intrusive massif. In order to control thus effectively the lines of intrusion of the granodiorites, the invaded sedimentaries must have been highly tilted previous to the time of igneous intrusions.

Observations made in southeastern Alaska and elsewhere show that the geologic processes which combined to produce these vast intrusions and structural phenomena acted very slowly and over long periods of time. Though the Coast Range intrusion is generally considered as having occurred at one period, a conclusion that is undoubtedly true for limited areas, it is probable that in southeastern Alaska, at least, considerable time intervened between the first granite invasion and the final solidification of the last intrusive masses. It is not possible now to refer these granitic intrusions in this province to a definite geologic period, but the evidence available in adjacent provinces indicates that they continued at least until late Middle Jurassic time. These invasions of igneous material were evidently the cause of the vast amount of metamorphism and deformation of the sedimentary strata along their contacts, and it is also probable that many of the ore bodies were deposited just after these igneous invasions, the intrusive containing the material forming the ore. The transfer of igneous material to points

[1] Brooks, A. H., Ketchikan mining district: U. S. Geol. Survey Prof. Paper 1, pp. 22-28, 1902. [2] Spencer, A. C., op. cit., p. 19.

nearer the earth's surface naturally produced strains in the earth's crust, which found relief in cracks and fissures and lines of brecciation at the contacts of the intrusives and elsewhere. The lines of weakness thus formed furnished channels that afforded free circulation for mineralizing solutions, which are believed to have been derived for the most part from the igneous masses themselves and to have been given off while the masses were in process of solidification.

A period of erosion appears to have followed the intrusion of the Mesozoic granite, and later another epoch of volcanism began. The volcanic rocks of this later epoch are represented by tuffaceous deposits and lavas that occupy considerable areas in the southern and western parts of Prince of Wales Island where they lie on the eroded surface of the granite and are overlain by or interstratified with deposits of plastic rock. The steeply tilted attitude and metamorphosed condition of these volcanic rocks indicate that they were considerably folded but that the structural deformation was not widespread, as it did not greatly modify the early Mesozoic folding which preceded the intrusion of the granite.

The deposition and folding of these Mesozoic strata appear to have been followed by a a long period of quiescence, during which erosion was probably extensive. In upper Eocene time sedimentation took place in local basins. The beds then formed, including fine conglomerate and shales with some lignite, were subsequently tilted and faulted, but this disturbance was apparently local. No evidence of marine life has been found in them and probably they were fresh-water accumulations. They occur only near sea level and in low-lying valleys and basins practically inclosed by mountains of granite and older metamorphosed rocks. These beds represent the most recent sedimentary formations of the Ketchikan district and after their deposition wide areas of land were flooded by basaltic lavas which poured forth through fissures in enormous volume. These lava flows are flat-lying and on Kuiu Island in the Wrangell district attain a thickness of over 1,500 feet. They were probably extruded at the close of the Eocene.

A large part of the Tertiary sediments may have been subsequently removed by erosion, for there must have been a long period of quiescence after their deposition and deformation. The next important event in the region was the development of the ice sheet which covered the entire district. Its retreat left the topography in essentially its present form. After the retreat of the ice some lava sheets were locally erupted.

GENERAL DISTRIBUTION OF MINERALIZATION.

Within the mainland belt and in the eastern part of Revillagigedo Island, in the Ketchikan district, mineralization is scattered both in the granitic intrusives and the adjacent schists, but mineralized zones corresponding to those in the Juneau gold belt to the north are less strongly marked. Quartz veins and metallic impregnations are found only locally, and prospecting has revealed comparatively few valuable ore deposits in the areas occupied by these rocks. Explorations have been confined, however, mainly to the shores of the deep, narrow fiords, from which the mountains rise abruptly to high altitudes. Steep, forest-covered slopes make prospecting difficult and have restricted the knowledge of the greater portion of the schist belt to the vicinity of salt water. The ore bodies thus far disclosed have been developed near Smeaton Bay in Behm Canal; at Sealevel, on the northeast side of Thorne Arm; and near the head of Carroll Inlet. For the most part they consist of simple veins in fissures and lode deposits of complex composition. They contain only moderate values in gold.

In the slate-greenstone belt, which borders Tongass Narrows and includes the western part of Cleveland Peninsula, ore bodies of considerable importance have been formed. They are largely lode deposits or mineralized bands, within which the greenstone schist country rock has been sheared and fissured and then permeated by the mineral-bearing solutions. In these mineralized bands or lode deposits the country rock has a bleached appearance and is impregnated with small cubes of pyrite and other sulphides. Local narrow seams of massive sulphide ore are found and native gold is seen here and there in the vein quartz or appears as thin films or flakes along the jointing cracks and slipping planes. Besides gold and small amounts of silver, copper also occurs in slight amounts in some of the deposits of these rocks.

Though quartz veins are prominent throughout the slate and greenstone belt, some of which show particles of native gold, most of them are too small or their gold content is too low to pay for mining.

On Prince of Wales Island the regularity of the rock structure is locally interrupted by broad, irregular areas of intrusive granitic rocks, and for this reason the ore bodies are not traceable along definite zones. Mineralization is in general closely related to the intrusive rock masses, and many of the deposits are at the contacts of the intrusives or in their vicinity. They occur as large lenticular bodies and as veins of nearly massive sulphide ore composed of pyrite, chalcopyrite, magnetite, and pyrrhotite in a matrix of garnet, quartz, calcite, and other gangue minerals. Such deposits are found on Copper Mountain and on Kasaan Peninsula. Bodies of copper ore inclosed in a greenstone schist country rock, both in lenticular masses and in veins, occur at Niblack Anchorage, at the head of North Arm, and in Hetta Inlet. Bornite and chalcopyrite occur in small patches that are in places disseminated through the granitic intrusives and are being explored on the Goodro claims to the northeast of Karta Bay.

On Prince of Wales Island gold ores are confined principally to the limestones and phyllites and are being mined in the vicinity of Hollis, on Cholmondeley Sound, and at Dolomi. At these points the gold occurs in veins of quartz and in lodes following lines of brecciation in the limestone. It is commonly present in the native form and is in many places accompanied by considerable amounts of silver and copper. The principal ore minerals are pyrite, galena, sphalerite, and tetrahedrite.

Auriferous veins in the granitic intrusives have been located and partly developed on Granite Mountain to the west of Karta Bay, at several points in the vicinity of Shakan, and at Ratz Harbor in Clarence Straits. These veins show that the granitic areas are not everywhere barren of ore, as often assumed.

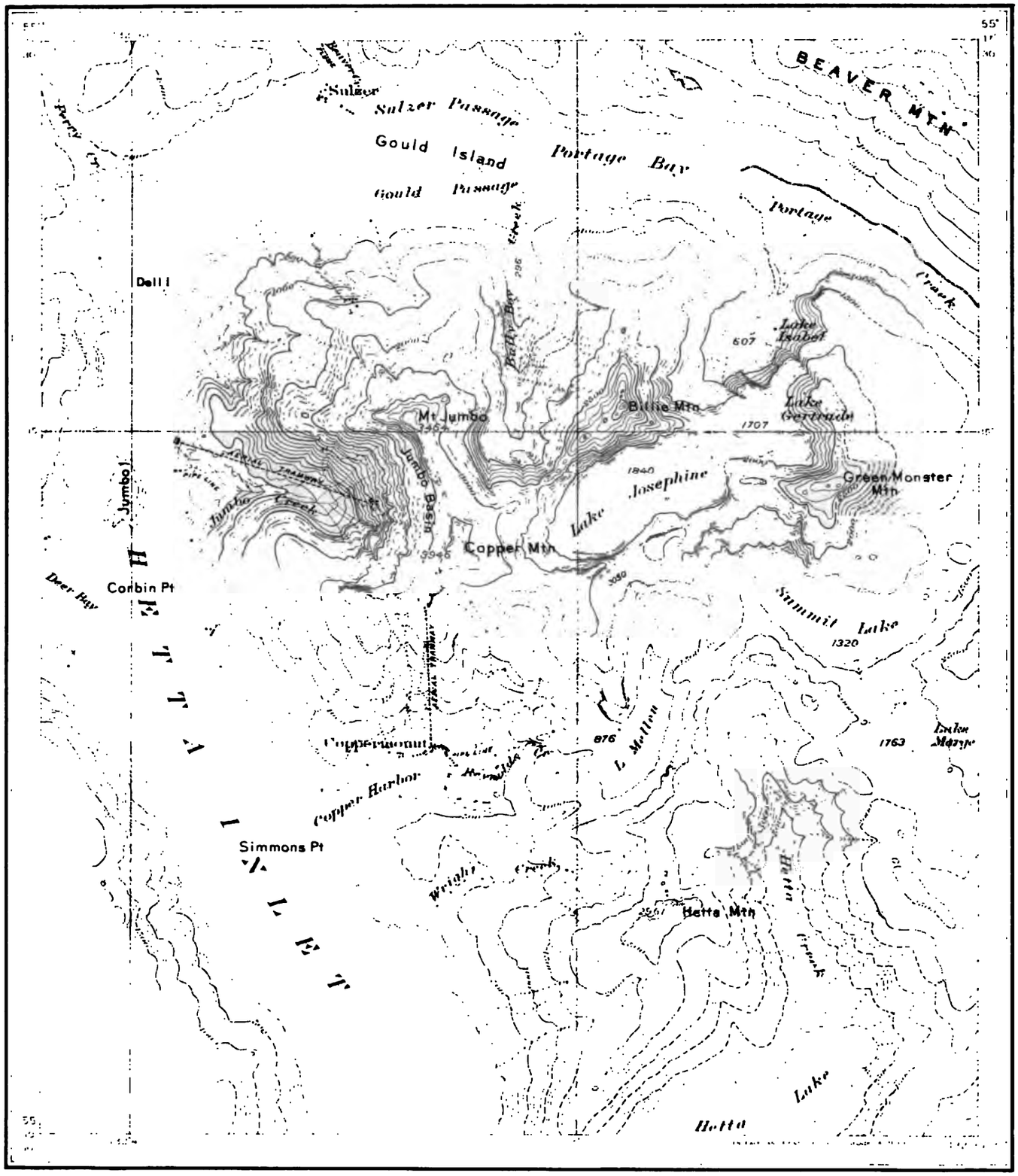
Ores of silver, lead, and zinc have been observed at several localities on Prince of Wales Island, though the only deposit that has been developed is on the Moonshine claim, in Cholmondeley Sound. At this place the ore occurs in a well-defined vein traversing the limestone and greenstone schist country rock.

COPPER MOUNTAIN AREA.

TOPOGRAPHY.

The Copper Mountain area as here defined embraces about 86 square miles of rugged country on the west side of Prince of Wales Island. (See Pl. II.) It takes its name from Copper Mountain (altitude, 3,946 feet), which marks the center of the area. This mountain and other peaks, such as Mount Jumbo (3,464 feet), Hetta Mountain (2, 961 feet), Billie Mountain (3,250 feet), Green Monster Mountain (2,900 feet), and their connecting ridges and spurs form a rugged highland which is bounded on the west and north by Hetta Inlet (see Pls. III, *A*, and IV, *B*), a deep embayment of Prince of Wales Island. On the east the upland merges into the unmapped mountains of Prince of Wales Island. Hetta Inlet is bounded on the north and west by highlands, only the lower slopes of which have been mapped. Among these is Beaver Mountain, about 3,000 feet in height, occupying the northeast side of the area here considered. Hetta Inlet is for the most part bordered by steep slopes that rise directly from the water or from a narrow rocky beach. Only at the mouths of the larger streams, like Portage, Reynolds, and Hetta creeks, are there any flats, and these are of small extent.

The drainageways are arranged radially, their heads centering around the higher peaks. The valleys have steep slopes and their upper parts have high gradients. Practically none of the valleys exceed 2 miles in length. Lakes are plentiful and occur at many altitudes, occupying basins from 100 to nearly 2,000 feet above sea level. The larger of these are Hetta Lake, in the southern part of the area, and Lake Mellen, Summit Lake, and Lake Josephine, in the central part. These lakes are of glacial origin. The heads of the valleys lie in amphitheater-like basins or glacial cirques, especially those on the northwest slopes of the mountains. Typical glacial cirques occur in Jumbo Basin, at the head of Jumbo Valley (see Pl. III, *A*), and in



TOPOGRAPHIC MAP OF COPPER MOUNTAIN AND VICINITY, ALASKA

Alfred H. [illegible]
Topography by R. H. Sargent.
Control by coast and geodetic surveys
and R. H. Sargent.
[illegible]

Scale 1/62500

1 ½ 0 1 2 Miles

1 ½ 0 1 2 Kilometers

Contour interval 100 feet

Datum is mean sea level

Dotted lines represent approximate topography

1914

A. VIEW NEAR HEAD OF HETTTA INLET.

Showing site of town of Sulzer and the character of the forests.

B. COPPER MOUNTAIN AND JUMBO BASIN.

Showing mine workings and general features of the geology of the mountain. Photograph by Winter & Pond.

A. GREEN MONSTER MOUNTAIN FROM SOUTH SIDE OF SUMMIT LAKE.
Photograph by Winter & Pond.

B. HETTA INLET LOOKING SOUTHWARD FROM COPPER MOUNTAIN.
Copper Harbor in the foreground. Photograph by Winter & Pond.

Hetta Basin, at the head of Wright Creek. The glacial character of the topographic sculpture in the area is further manifested by the occurrence of bowlders and gravel wash in the lower parts of the valleys and by glacial markings on some of the granite knobs.

The mountain slopes are covered with a luxuriant growth of timber and underbrush up to an elevation of 2,000 feet, the timber being useful to the mine operator, though the underbrush renders prospecting difficult. (See Pl. III, *A*.) The mountain lakes form large reservoirs which may furnish a supply of water for use in both mining and smelting.

A broad valley extending eastward from the head of Hetta Inlet and connecting by a low pass with a stream flowing into the head of Cholmondeley Sound furnishes a route of communication between the western and the eastern parts of the island. A wagon road about 4 miles long has been built across this pass.

GEOLOGY.

GENERAL FEATURES.

The general geology and mineral resources of this area have been briefly described in previous reports,[1] but a more detailed statement concerning the geology and ore deposits will be given here. The most striking geologic feature of the area is the irregular granitic intrusive mass that occupies its central part. (See Pl. V.) From this mass spurs or dikes 300 to 600 feet wide diverge into the surrounding series of metamorphic schists and the interstratified beds of limestone. The schists are much wrinkled and sheared and include both calcareous and siliceous varieties, and the limestones are generally marmarized. The rocks nearer the intrusive contact are further altered to a hornfels or amphibolite, which is usually banded with parallel beds containing much garnet and diopside. The principal limestone belt extends from Copper Harbor northwestward into Jumbo Basin, and another belt occurs on Green Monster Mountain (see Pl. IV, *A*) and Hetta Mountain. Narrow bands of schist are interstratified with these limestones, and in turn narrow beds of limestone are interstratified with the schists. Southwest of the main limestone belt on the west slope of Copper Mountain the limestone is overlain by a considerable thickness of altered siliceous schists, which lie conformably on the limestone and grade upward into a succession of amphibole and chlorite schists that are interstratified with quartzites and show no limestone. These chlorite and amphibole schists are interstratified with quartzites, slates, and here and there beds of a massive greenstone that probably represents an ancient lava. They border the east and west shores of Hetta Inlet (see Pl. IV, *B*) and are the most recent bedded rocks in the area.

SEDIMENTARY ROCKS.

The sedimentary rocks within the Copper Mountain area are, as already noted, made up of highly metamorphosed schists and limestones, probably chiefly of Paleozoic age (Carboniferous?). They occupy a steeply tilted position surrounding the granitic intrusive mass. These stratified rocks fall into two divisions—a lower, made up of metamorphic schists and limestones, and an upper, made up of volcanics with some clastics. The distribution of these rocks is indicated on the geologic map. (See Pl. V.)

SCHISTS.

The oldest rocks of the Copper Mountain area are made up of metamorphosed schists composed largely of sedimentary material, though in places they include tuffaceous material and extensive limestone beds. These rocks surround the granitic intrusive masses and are important because of their relations to and influence on the ore deposits.

The schists are for the most part fine grained and crystalline, with amphibole, mica, and quartz as their principal mineral constituents, though in some feldspar, calcite, or chlorite

[1] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of southeastern Alaska: U. S. Geol. Survey Prof. Paper 1, 1902. Brooks, A. H., and others, Report on progress of investigations of mineral resources of Alaska in 1905: U. S. Geol. Survey Bull. 284, 1906; Report on progress of investigations of mineral resources of Alaska in 1906: U. S. Geol. Survey Bull. 314, 1907; Mineral resources of Alaska (report on progress of investigations in 1907): U. S. Geol. Survey Bull. 345, 1908; Mineral resources of Alaska (report on progress of investigations in 1908): U. S. Geol. Survey Bull. 379, 1909.

may predominate, and at points near the granitic intrusives they are composed essentially of garnet, epidote, or diopside, with quartz and some magnetite or pyrite. Certain strata consist of carbonaceous, argillaceous schists with local development of graphite; phyllites also occur. Some of the specimens collected resemble a biotite gneiss; they are massive, though much wrinkled, and from the hand specimens their origin is difficult to determine. Calcareous bands occur in these more gneissic schists, and on their weathered surface are projecting ribs of biotite with some quartz.

These rocks are presumably derived for the most part by alteration from argillaceous and calcareous sediments that have been largely crystallized by intense metamorphic action, though some of the schistose strata may represent metamorphosed igneous rocks of volcanic origin.

LIMESTONES.

Thickness and character.—Beds of altered limestone are interstratified with the schists and evidently belong to the same period of deposition. These beds range in thickness from less than 100 feet to more than 1,000 feet. The limestone varies from a white, coarse, crystalline marble to a dark-blue to nearly black, in places finely crystalline to granular though locally thin-bedded and slaty limestone. This change in appearance is due not so much to a change in composition as to a change in alteration or crystallization, this being in part attributable to contact metamorphism caused by the granitic intrusives and in part to regional metamorphism.

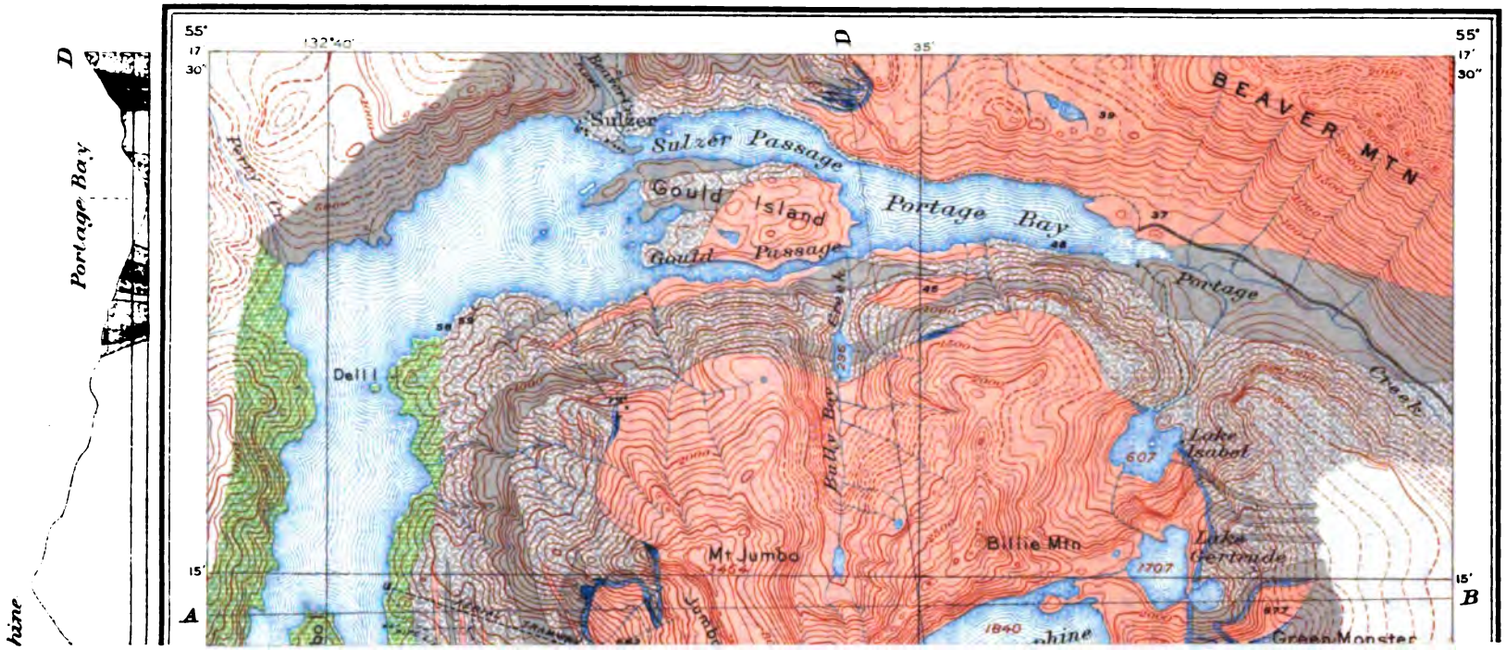
In the hand specimen the crystallized limestone is white with occasional gray patches, granular in texture (average granularity about 1 millimeter), and consists almost entirely of calcite. Under the microscope it appears to be composed almost exclusively of lime carbonate, with rarely a speck of magnetite. The carbonate is evenly granular and intricately twinned.

This rock is the country rock into which the granodiorite of the Jumbo property is intruded and along the narrow margin of which the copper-bearing contact deposits have been formed. An analysis of the limestone from this mine, by George Steiger, is as follows:

Analysis of limestone from Jumbo mine.

SiO_2	0.61
Al_2O_3	.30
Fe_2O_3	.48
MgO	8.00
CaO	46.45
H_2O	.22
CO_2	44.07
S	.06
MnO	.03
	100.22

Occurrence.—These schists and limestones form a nearly continuous belt around the granitic mass which occupies the central portion of the area. In places the limestone members are at the contact, though in general the schists border the intrusive mass. The total thickness of these rocks is difficult to determine because of the folding and compression to which the rocks have been subjected, but it is probably 5,000 feet or more. In Jumbo Basin a wide mass of schist and limestone, which also extends southward over Copper Mountain, is completely surrounded by the intrusive rock. Tongues and small masses of the granitic rock are surrounded by the schists. Near the intrusive contact in the upper part of Jumbo Basin the limestones are marmarized and the schists are silicified or garnetized, whereas lower in the valley, at points away from the contact, the limestone is a blue, finely crystalline rock and the schists are more argillaceous and slaty. On the shore of Hetta Inlet opposite Gould Island and on the mountain slopes the schists and limestones are highly altered and are crosscut by granitic and pegmatitic dikes. They have a general east to northeast trend, approximately parallel to that of the intrusive contact. Some of the strata are mineralized with pyrite and contain also some chalcopyrite. In places they are much wrinkled and resemble gneissoid rocks. On Green


55°
17′
30″
132°40′
35′
55°
17′
30″
D
D
Portage Bay
Sulzer
Sulzer Passage
Gould Island
Gould Passage
Portage Bay
BEAVER MTN
Portage Creek
Dell
Baldy Bay
Lake Isabel
Mt Jumbo
Billie Mtn
Lake Gertrude
Green Monster
15′
15′
A
B
607
1707
1840
LEGEND
Contact rock
(associated ore bodies in darker color)
Granitic intrusives
Greenstone schist
Limestone
Metamorphic schist
MESOZOIC
PALEOZOIC AND MESOZOIC?

Monster Mountain and along the ridge just north of it the schists and limestones form narrow interstratified belts, 50 to 500 feet wide, striking in a west to northwest direction, nearly at right angles to the intrusive contact. The limestones are marmarized though somewhat siliceous, and the dominating schist is a brown mica-quartz schist, much wrinkled and containing quartz seams. On the south side of Summit Lake a belt of altered schist about 300 feet wide is included in the granite. This belt strikes southwest and has a nearly vertical dip. It is almost entirely altered to contact rock, its original schistose structure having nearly disappeared, but it shows a distinct banding of the amphiboles and mica, and the adjacent granite includes fragments which may have been derived from the schist.

The basic amphibole schists and the siliceous mica schists both occur on Hetta Mountain and along the southern contact of the intrusive mass, the former on the east slope and the latter on the west slope. The schistosity is nearly at right angles to the intrusive contact and the schists appear to be more compact and show more wrinkling than at the points where they lie parallel with the intrusive contact.

The limestone that forms a belt near Hetta Mountain is a white to bluish crystalline rock and is cut by several granitic dikes.

Age.—These limestones and schists resemble both stratigraphically and petrographically the metamorphic rocks adjacent to the Coast Range batholiths along the seaward side of the mainland. (See p. 16.) The rocks bordering the mainland have been described as the Ketchikan series by Brooks and as the schist band by Spencer. Fossils found in the mainland belt of limestones indicate that they include Carboniferous and probably some Mesozoic strata.

Structure.—Cleavage is usually well developed in the schists where they contain considerable amphibole or mica. The more siliceous beds and those near the contact of granitic intrusives that contain infiltrations of garnet, diopside, or epidote, and also the limestones, do not show this pronounced cleavage but in places show cleavage at right angles to the bedding. It is noteworthy that the lines of schistosity correspond to those of the bedding, a fact that is made evident by the occurrence of the interstratified limestone beds. The stratification of these bedded rocks is indicated at many points on the geologic map by symbols indicating strike and dip. It is clear that the present structure is in large measure due to the influence of the intruded granitic mass. The beds farther south strike northwestward, at right angles to the granite contact, though those on the west and east sides of the granite mass are parallel to the contact both in strike and dip, as are some of those on the north side of the main intrusive mass, where the bedded rocks have an east-west strike and almost vertical dip, and occupy a position between two main granitic masses. (See Pl. VI, *A*.)

Metamorphism.—The alteration of these rocks to crystalline schists is ordinarily attributed to regional metamorphism, which is supposed to have been produced by mountain-building forces operating when the rocks were deeply buried. It is probable that the general metamorphism was effected at an earlier date than that of the granitic intrusion, though a considerable amount of metamorphism may be attributable to the intrusion of the granitic masses. The alterations due to contact metamorphism are considered elsewhere in this report.

GREENSTONE SCHISTS.

Character.—The succeeding strata differ somewhat both in composition and origin, but are principally greenstone schists composed largely of igneous material interbedded with some siliceous sedimentary material. They consist of amphibole and chlorite schists and quartzites. and contain, in places, argillaceous interstratified beds of phyllite and graphitic schists.

The greenstone schists probably represent altered andesite or diabase tuffs and lavas. Their component minerals, most of which are secondary, are in the main amphibole, altered plagioclase feldspar, epidote, chlorite, calcite, quartz, and magnetite. The original plagioclase feldspar is generally altered to zoisite and muscovite and the pyroxenes are changed to amphibole. The microscope shows that the less altered greenstone schists were derived from an igneous rock, probably an augite andesite. The augite, however, is represented by amphibole

that occurs in minute needles. The minerals differ in amount in different strata and the rock may be called amphibole schist, actinolite schist, chlorite schist, calcareous schist, or siliceous schist, its designation depending on its mineral composition.

These greenstone schists grade without definite boundaries into a rock composed partly of igneous and partly of sedimentary material, and this in turn grades into a quartzite or a siliceous argillite, composed mainly of sedimentary material. The intercalation of the greenstone schists with the sedimentary beds suggests that they represent extrusives of igneous material thrown out over the sea bottom as volcanic tuff and in some places as a lava bed.

Included quartzite.—The sedimentary beds interstratified with the greenstone schists are indurated, fine-grained to aphanitic rocks, in places showing banded layers, and ranging in color from light gray to dark green. They usually contain pyrite and weather brown on the surface. They do not break easily along the bedding planes but fracture more readily along joint cracks, breaking at right angles to the bedding.

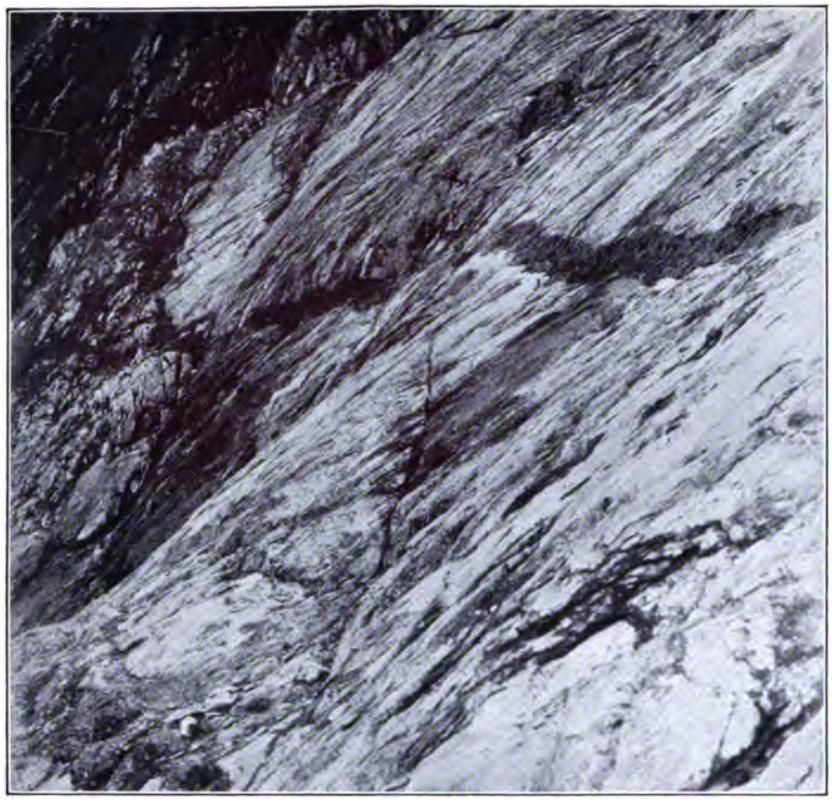
Occurrence.—The greenstone schists border both sides of the main northwest channel of Hetta Inlet, but do not extend along its eastern branch. (See Pl. I.) On the west slope of Copper Mountain they extend to an elevation of about 1,000 feet, where the interstratified greenstone schist members gradually disappear and the quartz-mica schists of the older series are found. No sharp line of demarcation can be drawn between these two formations, and the division is made where the greenstone volcanic material ceases to occur in the stratified rocks.

Near the shore line at the foot of Copper Mountain certain strata of the greenstone schists have a bleached appearance and are of a pale-green color. These rocks contain both pyrite and chalcopyrite as well as quartz stringers and kidneys of quartz and calcite. In places these mineralized strata contain large amounts of copper.

Age.—The greenstones and associated sediments of the Copper Mountain area resemble lithologically the rocks of the mainland belt already described (p. 16). Here, however, the quartzites dominate over the slates. As in the mainland belt, the greenstones are closely associated with limestones that are believed to be of Carboniferous age. In the Copper Mountain region, however, they are clearly younger than the limestones. The slate, graywacke, and greenstone belt of the mainland is in part, at least, Mesozoic, and in the absence of evidence to the contrary it is therefore fair to assume that the greenstones of Copper Mountain are also of Mesozoic age.

Structure.—The structure of the greenstones is much simpler than that of the older schists and limestones. These rocks strike north to northwest and dip NE. 30° to 75°. On the east shore of Hetta Inlet the dip is usually 15° to 30° less than along the west shore. They overlie the metamorphic schists with apparent conformity. They show prominent jointing planes, especially along the west shore of Hetta Inlet, and these strike in general from N. 75° W. to N. 75° E., nearly at right angles to the schistosity, though their dip is almost vertical. Dikes of diabase and basalt, cutting the greenstones and invariably following the direction of the jointing planes, are common.

Metamorphism.—The metamorphism of the greenstones is similar to but less intense than that of the schists and limestones already described. It was doubtless produced by the same forces and during the same periods. The associated sedimentary rocks were originally sandstones, shales, and tuffs, more or less intermixed. The sandstones have been changed to quartzite, the shales to carbonaceous and sericitic schists, and the tuffs to chlorite schists, and just as these originally sedimentary rock beds graded one into the other so do their metamorphic representatives. The metamorphic processes that effected these changes caused a breaking up of the original minerals into secondary minerals, such as the alteration of feldspar to kaolin and sericite and of hornblende and pyroxene to chlorite, serpentine, calcite, and quartz. The combination of these minerals by metamorphism forms other minerals, such as andalusite and staurolite, but such occurrences were rarely noted in the Copper Mountain area.



A. SILICEOUS SCHISTS ON MOUNTAIN SIDE BELOW NEW YORK CLAIM.
Showing basic dike crosscutting the schists. Elevation, 2,500 feet.

B. CONTACT ORE DEPOSIT ON NEW YORK CLAIM, COPPER MOUNTAIN.
Crystalline limestone on right; altered granitic intrusive rock on left.

IGNEOUS ROCKS.

GENERAL FEATURES.

The detailed petrographic and microscopic study of the igneous and contact rocks of this region was kindly undertaken for the writer by Dr. H. E. Merwin, of the Geophysical Laboratory of the Carnegie Institution of Washington. The results of Dr. Merwin's investigations are given in detail in this report.

Coarse-grained massive igneous rocks, occurring as batholiths, occupy nearly half the surface of the Copper Mountain area. Collectively these rocks are commonly called granite, and they have all been mapped in one color under the name of "granitic intrusives." They comprise, however, rocks of several types, which differ widely in composition, and in some places a change in mineral components was noted from part to part of the same mass. These granitic intrusive rocks form the most important geologic feature in the area, principally because the main ore deposits are found at their contacts and were formed at the time of their intrusion. The relations of these intrusives to the ore deposits and the phenomena observed at the contacts are discussed at length in this report.

Other intrusive rocks of minor extent occur within the area in the form of dikes. These dike rocks include granite porphyry, diorite porphyry, pegmatite, aplite, lamprophyre, diabase, and basalt.

GRANITIC INTRUSIVES.

TYPES.

The batholith rock masses in the Copper Mountain area include granitic intrusives of several distinct types, their differences depending largely on the proportions of their component minerals. The factor of greatest influence in determining the rock type is the presence and proportion of orthoclase feldspar. The main type is a diorite, though the proportion of orthoclase may increase in different parts of the same batholithic intrusive mass, and the rock must then be classed as monzonite or, where orthoclase dominates the rock, as syenite. No well-defined lines can be drawn between such variations of the rock type; it is possible to recognize them only by microscopic study of specimens.

These rocks include few true granites, as the proportion of quartz they contain is generally small. A basic type of the granitic intrusives is represented by the gabbros that form some of the smaller batholithic masses. The distinctions between the different rock types are emphasized in the petrographic descriptions.

DIORITE.

The diorite is a coarse to medium grained rock, light to dark gray in color, made up essentially of plagioclase feldspar and hornblende, though in places containing biotite and occasionally pyroxene, as well as small amounts of orthoclase and some quartz, magnetite, titanite, and apatite. The central portions of the diorite batholiths are rather uniform in composition and texture, though near the contact they become less uniform in color and are marked by dark spots, most of which are segregations of hornblende, and in places they are traversed by veins of pegmatite. A type specimen of the diorite (specimen J 4) collected in Jumbo Basin near the mine on Jumbo No. 4 claim, though far enough back from the contact to be free from all secondary alteration, is described below.

The type specimens of diorite were collected principally from Jumbo Basin (specimens 662, 645 to 649) and Beaver Mountain (specimens 39 and 37). They include both hornblende diorite and augite diorite, which in appearance are practically the same as the granodiorite. Rocks of these two types make up the greater part of the granitic intrusives, and it is not possible to define them separately as regards their distribution, as the one evidently grades into the other.

The microscopic petrography of these rocks is described below by Dr. H. E. Merwin.

Specimen J 4: A granitoid rock of medium grain, containing about the following percentages of essential mineral constituents: Quartz, 10; plagioclase, 50; orthoclase, 30; hornblende, 5;

augite, 5; and small amounts of accessory biotite, apatite, titanite, and magnetite. The plagioclase ranges from labradorite to oligoclase, averaging about Ab_2An_1. The central, more calcic zones are altered to epidote.

An analysis of the rock by George Steiger and a calculation of the normative mineral composition is as follows:

Analysis of specimen of diorite from Jumbo Basin.

SiO_2	59.44	TiO_2	0.66
Al_2O_3	17.40	ZrO_2	None.
Fe_2O_3	3.30	CO_2	None.
FeO	2.77	P_2O_5	.28
MgO	1.81	S	.02
CaO	6.51	MnO	.17
Na_2O	4.22	BaO	.07
K_2O	3.12	SrO	.05
H_2O-	.06		
H_2O+	.56		100.44

Mineral composition of specimen of diorite from Jumbo Basin.

Quartz	8.94	Magnetite	4.87
Orthoclase	18.35	Ilmenite	1.37
Albite	35.63	Apatite	.67
Anorthite	19.46	(Water)	.62
Diopside	8.68		
Hypersthene	1.93		100.52

It is evident that the single slide examined did not closely represent the rock analyzed, particularly in respect to the proportion of normative orthoclase and plagioclase. It should be borne in mind, however, that the amount of orthoclase in a rock may be considerably greater than the amount of pure potassium feldspar, on account of the albite which may be held in solid solution. The normative composition places the rock in the group andose.

Specimen 662. Collected from main intrusive mass on trail 500 feet below head of aerial tram, Jumbo Basin.

A granitic rock of medium-grained texture and greenish-gray color. It consists of plagioclase, pyroxene, and biotite, the dark-colored constituents composing 35 to 40 per cent of the rock. In the thin section the plagioclase appears in anhedral grains zoned and twinned. It averages about Ab_2An_1 in composition, ranging from oligoclase to labradorite. The pyroxene is in subhedral grains, nearly colorless except in uralitized areas, where it is greenish. Small grains of plagioclase are included in the pyroxene, which constitutes about 30 per cent of the rock and is essentially augite, but includes some diopside. About 5 per cent of interstitial orthoclase is present. Accessory minerals are biotite, quartz, magnetite, and apatite in relatively large prisms; also titanite.

The rock is an augite diorite.

Specimen 8. Collected from branch of main intrusive mass on south side of Jumbo Basin at an elevation of 2,500 feet.

Both in the hand specimen and in the thin section this rock resembles specimen 662, collected from the main intrusive mass of Jumbo Basin, but it is slightly finer grained and contains zircon.

Specimen 643. Collected from main intrusive mass northeast of head of aerial tram in Jumbo Basin at an altitude of 600 feet.

This rock is medium grained, light gray, and consists of plagioclase and hornblende and small amounts of orthoclase, quartz, pyroxene, and titanite. The plagioclase is zoned andesine, and constitutes 60 per cent of the rock. The hornblende is pleochroic in bright greens and light yellows and some of it contains irregular kernels of diopside. Quartz is a very minor constituent. Orthoclase is abundant, comprising about 20 per cent of the rock. The accessory minerals are biotite, magnetite, apatite, titanite, and zircon.

The rock is a hornblende diorite differing from the preceding in containing much more orthoclase and hornblende instead of augite.

Specimen 39. Collected from intrusive mass of Beaver Mountain north of head of Portage Bay at an elevation of 1,000 feet.

A gray granitic rock of medium grain, showing plagioclase and much hornblende and orthoclase. The slide contains about 40 per cent of zoned oligoclase and labradorite, and 35 per cent of poikilitic hornblende inclosing plagioclase, apatite, magnetite, and kernels of diopside. It is remarkably pleochroic, ranging from bright greenish blue to light yellow-brown and deep brown. It contains 15 per cent of interstitial orthoclase. The accessory minerals, which amount to about 7 per cent, include diopside, biotite, magnetite, titanite, and apatite.

This rock is a hornblende diorite.

Specimen 37. Collected from intrusive mass of Beaver Mountain, at head of Portage Bay.

This diorite is similar in appearance to specimen 39, though it includes larger flakes of biotite and, as seen in the thin section, less hornblende, in place of which it contains from 5 to 10 per cent of diopside and augite. It carries also more orthoclase, containing at least 25 per cent.

GRANODIORITE.

The granodiorite is a medium to coarse grained hypidiomorphic light-gray rock composed essentially of oligoclase feldspar, quartz, orthoclase, and hornblende or biotite. Common accessory minerals are pyroxene, titanite, apatite, and magnetite.

Type specimens of the granodiorite were collected from the main intrusive mass along the shore of Mellen (specimen 133) and Summit lakes and from adjacent batholithic masses on the shore of Hetta Lake (specimen 127) and on Green Monster Mountain (specimen 677). At these localities the rock is practically fresh, showing little or no development of secondary minerals. In composition it is apparently uniform and shows little or no segregation of minerals.

The microscopic petrography of the specimens was studied by Dr. H. E. Merwin and is described below.

Specimen 133. Collected from main intrusive mass at point on north side of Lake Mellen. The hand specimen is medium grained, grayish, and contains well-formed prismatic crystals of hornblende and much plagioclase; also some quartz and orthoclase. Under the microscope the rock shows about 60 per cent plagioclase in subhedral crystals polysynthetically twinned and zoned. The composition of the zones varies from albite to andesine. The hornblende, the other chief constituent, is light yellow to deep green and contains inclusions of plagioclase, titanite, apatite, and magnetite. About 10 per cent each of quartz and orthoclase occurs interstitially. Diopside appears as an accessory; also titanite, magnetite, and apatite.

The rock is a hornblende granodiorite.

Specimen 127. Collected from intrusive mass on north side of Hetta Lake, on the west side of the peninsula.

This rock is decidedly coarse grained, its texture being due in part to the distribution of biotite. Plagioclase, quartz, and orthoclase are the light-colored constituents. Many of the plagioclase crystals are 8 millimeters in length; the biotite scales are 4 millimeters in diameter, and the grains of quartz and orthoclase are somewhat smaller. In the thin section the average of the plagioclase is basic oligoclase or acidic andesine, and the crystals are decidedly zoned. This mineral constitutes about 60 per cent of the rock; quartz, 20 per cent; biotite, 15 per cent; orthoclase, 5 per cent. The accessory minerals are apatite, titanite, and magnetite.

This rock may be classed as a biotite granodiorite, though the specimen examined contains little orthoclase.

Specimen 677. Collected from center of small mass just north of Green Mountain.

A gray medium-grained granitoid rock which in the hand specimen shows as essential constituents plagioclase, orthoclase, quartz, hornblende, pyroxene, and subordinate magnetite and titanite. In the thin section the plagioclase is subhedral and shows pronounced zonal structure, the zones ranging in composition from oligoclase to central cores of labradorite, which are partly altered to epidote. The plagioclase, averaging basic oligoclase, constitutes about

40 per cent of the rock. Orthoclase, with some microcline, is abundant, constituting as much as 25 per cent of the slide studied. Common hornblende and uralite form 10 per cent of the rock; diopsidic augite, 10 per cent; titanite, 2 per cent; and apatite, 1 per cent. Interstitial quartz forms about 10 per cent of the rock.

But for its association this rock might be classed as a monzonite.

SYENITE.

The syenites are medium-grained light-gray to pale-pink rocks composed essentially of orthoclase and plagioclase (oligoclase variety) in different proportions, with hornblende as the principal dark mineral and pyroxene, magnetite, apatite, and titanite as accessories. The type of rock is determined largely by the amount of orthoclase present in the specimen. Where the proportion of orthoclase is much less than that of plagioclase the rock becomes a granodiorite or diorite. In the field it was not possible to recognize these distinctions.

The syenite forms a part of the batholithic masses occurring near its margin (specimens 626 and 121). It is also found in outlying dikes and in tongues branching from the main intrusive masses (specimen 128).

Specimen 626. Collected at point near contact of main granitic mass 1,000 feet east of Jumbo No. 4 mine at an elevation of 3,000 feet.

This is a medium to fine grained granitic rock containing much orthoclase, some pyroxene, plagioclase, and quartz. The visible accessories are pyrite, magnetite, and titanite. Geometric analysis under the microscope shows that the orthoclase constitutes 75 per cent of the mass of the rock. It occurs in subhedral, markedly perthitic crystals, nearly adjacent crystals being separated by a narrow band of quartz and plagioclase. Plagioclase, which composes 5 per cent of the rock, occurs in definitely bounded crystals, some of which form the nuclei of orthoclase crystals. The plagioclase is zoned and twinned according to both the Carlsbad and albite laws. It is essentially albite and oligoclase. The quartz is entirely interstitial and comprises about 10 per cent of the rock. The pyroxene, diopside, which amounts to 8 per cent, is anhedral. Well-formed apatite crystals are both included in and adjacent to the diopside.

The rock is a potash syenite.

Specimen 121. Collected from bluffs in creek just west of Lake Mellen at contact of main intrusive mass.

This is a grayish medium-grained granitoid rock, which in the hand specimen shows orthoclase, plagioclase, and hornblende. In thin section the zoned and subhedral plagioclase was determined to be albite and oligoclase, which constitute perhaps 50 per cent of the rock. The orthoclase is interstitial and amounts to 20 per cent; the hornblende, which occurs in rough prisms, forms 10 to 15 per cent; and the quartz about 5 per cent. The accessory minerals are pyroxene, magnetite, apatite, and titanite.

The rock is a hornblende syenite.

Specimen 128. Collected from dike rock cutting schists on east side of Hetta Lake.

This is a light-gray medium-grained rock of granitic and porphyritic texture. Orthoclase, some plagioclase, and quartz, together with small amounts of hornblende and titanite, are easily distinguished in the hand specimen. Plagioclase (albite and acidic oligoclase) composes about 50 per cent of the rock and occurs in large, regularly bounded crystals. Interstitial orthoclase constitutes 35 per cent of the rock. Quartz grains are plentiful, making up 15 per cent of the rock. Hornblende, diopside, biotite, magnetite, and titanite are the accessory minerals.

This rock is quartz syenite.

GABBRO.

The gabbros are made up of the more basic minerals, largely hornblende and pyroxene with a plagioclase feldspar, usually labradorite, and little or no quartz, and thus the percentage of silica is lower than in the other granitic intrusives. It is difficult in places to distinguish this rock from the diorite, as the two differ mainly in the variety of plagioclase feldspar they contain.

The gabbro constitutes some of the smaller batholithic masses occupying areas adjacent to the main granitic batholith (specimens 45 and 98). Another type of gabbro is found in dikes that cut the sedimentary rocks, but these dikes belong to another period of intrusion and are formed of a coarse phase of porphyrite or diabase. They are described under the heading "Dike rocks," on page 39. Dr. Merwin's petrographic descriptions follow:

Specimen 98. Collected from small intrusive mass three-fourths mile southwest of Hetta Mountain.

This is a dark-gray, coarse-grained rock with large hornblende prisms, grains of pyroxene, plagioclase, and magnetite. The dark crystals compose nearly 70 per cent of the rock. In thin section the hornblende is seen to be poikilitic, including crystals of plagioclase and pyroxene. In certain crystals an inner zone without inclusions has a greenish color. The other minerals are zonal plagioclase (labradorite), which compose 15 per cent of the rock; interstitial orthoclase, forming 7 per cent; and greenish pyroxene, slightly uralitized, forming 10 per cent. Accessories are magnetite, apatite, titanite, and some biotite.

The rock is a hornblende gabbro.

Specimen 45. Collected from intrusive mass on the south side of Portage Bay at an elevation of 500 feet.

A dark-gray, medium-grained rock containing long crystals of hornblende, which form the greater part of it, the remainder consisting of labradorite (20 per cent) and pyroxene (10 per cent). The accessory minerals are magnetite, apatite, titanite, and biotite.

The rock is a hornblende gabbro.

DISTRIBUTION OF THE IGNEOUS ROCKS.

The granitic intrusives constitute the core of the mountain mass that occupied the center of the area indicated on the map as composed of igneous intrusives. There is no evidence that this batholithic mass represents more than one period of intrusion, for it is uniform in character throughout, though the composition of the rock of which it is formed is variable. In the main Copper Mountain and Beaver Mountain masses at some distance from the contact the prevailing rock is uniform in grain and color and ranges in composition from granodiorite to diorite. Near the contact orthoclase occurs locally in amounts sufficiently large to make the rock a syenite. Representative specimens of the syenite were collected at a point one-half mile west of the summit of Copper Mountain, near the border of the Copper Mountain mass (specimen 626). The granodiorite, as is shown by specimens 127 and 133, forms the shore lines of Hetta Lake, Lake Mellen, and Summit Lake. On the west slope of Jumbo Basin, between Copper Mountain and Mount Jumbo, the diorite dominates (see specimens 643 and 662) and forms steep cliffs, locally called the Palisades, which show columnar structure due to jointing planes. The rocks of these cliffs are noteworthy, as the dark constituent of the diorite in their upper part is principally augite, whereas near the contact it is principally hornblende. The huge blocks of diorite that have fallen from these cliffs would make good building stone.

STRUCTURAL FEATURES.

The main structural features of the granitic intrusives observed on the surface exposures are shown on the areal geologic map, and their probable underground extensions are shown on geologic cross sections. The structural relation of the intruded rocks to the intrusives has already been mentioned. No pronounced structural breaks occur within the granitic intrusive masses. The joint planes follow two principal directions—northwest and northeast—and have deeply inclined to vertical dips. Near the borders of some of the masses are fractures filled with later intrusive dike rocks or quartz-feldspar veinlets. Faults of structural importance were not observed.

The joint planes and fractures near the borders of the batholithic masses are generally supposed to have been produced by forces developed when the magma was cooling.

The underground form or limit of the batholithic mass is shown by the attitude of its contact surfaces, which, except at a few places, dip under the intruded rocks at an angle of

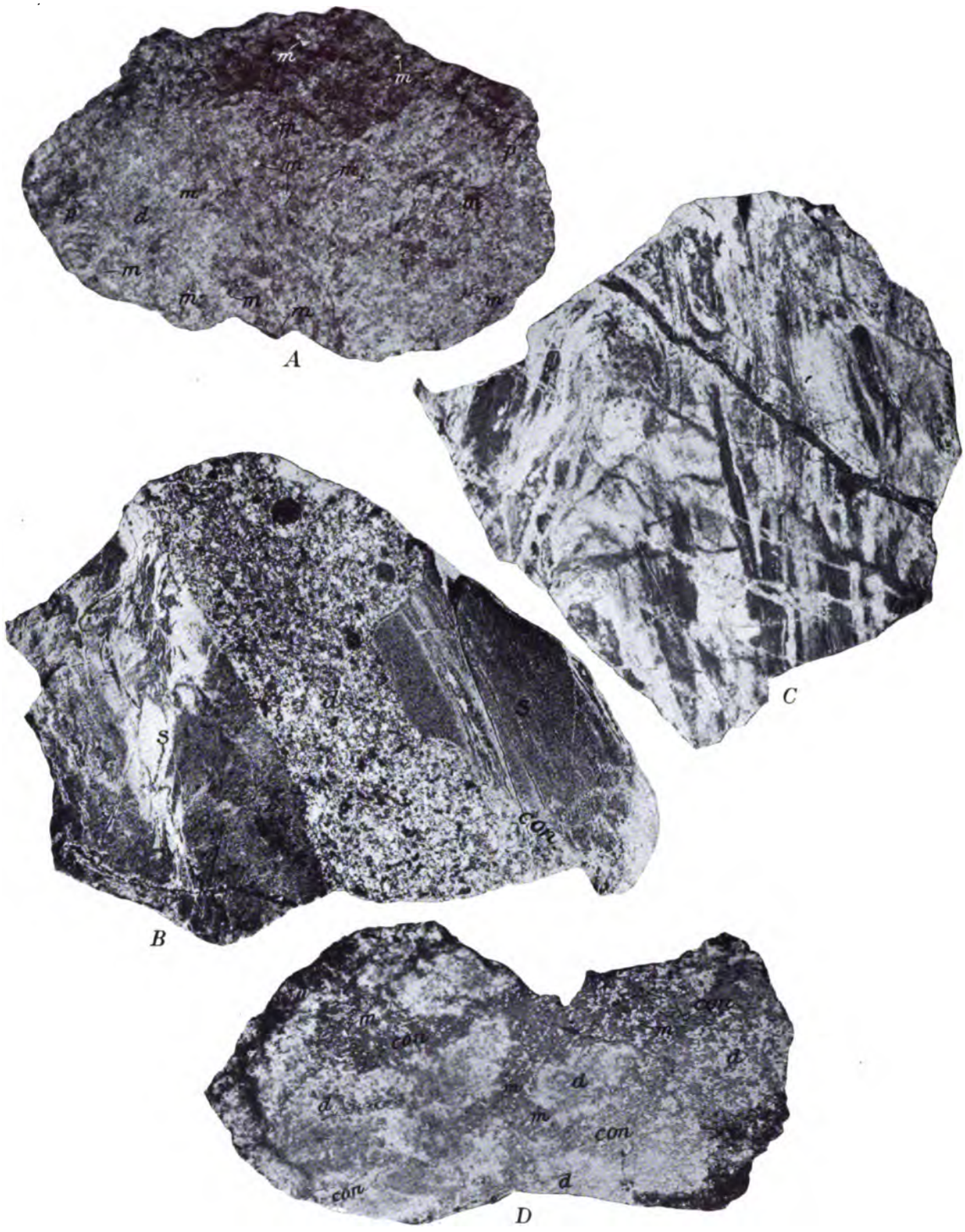
PLATE VII.

A. Altered diorite from the contact zone on Jumbo claim No. 4. The granitic texture is partly preserved though the feldspars are altered to scapolite and the amphiboles to diopside. Throughout the rock are small reflecting flakes of molybdenite, which are represented on the plate by the small white specks. *d*, Altered diorite; *m*, molybdenite; *p*, pyrite.

B. Fragment of schist from Jumbo claim No. 1, containing abundant pyrite, pyrrhotite, and magnetite. Such fragments of various sizes are included in a hornblende diorite. Many of the fragments are bordered by narrow rims (0.5 millimeter wide), which appear to be due to alteration by the diorite. *d*, Diorite; *s*, metamorphosed schist; *con*, contact of included schist, poorly defined, owing to partial absorption by igneous rock.

C. Metamorphosed schist adjacent to granite contact, which has been fractured and interstices filled with feldspar, quartz, and garnet. Specimen from Jumbo claim No. 1. The dark schistose bands contain plagioclase, quartz, and biotite. The dark vein contains diopside and plagioclase. The light patches are plagioclase with some quartz.

D. Altered diorite from contact zone on Jumbo claim No. 4. This specimen shows the diorite more altered than in *A*. Only patches of the granitic rock are preserved, surrounded by the contact rock, which is made up essentially of diopside and calcite with scattered grains of chalcopyrite. *d*, Altered diorite; *m*, molybdenite; *con*, contact rock containing scattered grains of chalcopyrite.



ROCKS FROM ZONE OF CONTACT OF SCHISTS AND DIORITE IN COPPER MOUNTAIN AREA.

about 70°. The relation of the intruded and intruding rocks is well exposed in many gulches that traverse the contact, the granitic rock forming the bed of the gulch and schist or limestone forming the banks. The structure of the intruded rock beds apparently had little influence on or control of the intrusion of the main masses, for the intrusion evidently determined the present position of the bedded rocks. The larger dimensions of most of the smaller granitic masses, however, lie in the bedding planes of the stratified rocks.

MARGINAL PHENOMENA.

The margins of the granitic intrusives show various noteworthy phenomena. The margin of the main granitic mass is in places irregular, forming deep bays, whereas at other points it forms nearly straight lines. Wide areas of the intruded schists are included within the intrusive mass and tongues of the intrusives branch out into the schists. At the margin of the intrusives there are many included fragments of the intruded rock of various sizes, ranging from minute pieces to masses several feet in diameter, and parts of some of these appear to be replaced by minerals that compose the intrusive. (See Pl. VII.) No faulting occurs at the margin of the intrusive or intruded rock and only small disconnected displacements in the rocks were noted. The intruded schistose beds are usually bent to conform with the contact of the intrusive masses, though in places they are much crinkled and squeezed or even brecciated. In general, however, it may be assumed that the intrusion of the granitic rocks took place at depths below the zone of faulting and fracturing, where the rocks were under pressure so great that they were very flexible. At certain points, however, a good example being in the lower tunnels on Jumbo No. 2 claim, the main intrusive mass has penetrated an area of brecciated schists, filling the interstices between the fragments and partly replacing them. Such phenomena are not uncommon at the contacts of most of the intrusive masses in southeastern Alaska. A change in the composition of the intrusive rock at points adjacent to ore-bearing zones is characteristic of the Copper Mountain area. Near the immediate contacts of the intrusive mass at these places diopside and orthoclase are the dominant mineral components, and scapolite or wollastonite occurs in abundance between the intrusives and the contact rock.

AGE.

It is evident that the granitic intrusives are more recent than the greenstones, which are the most recent bedded rocks in the Copper Mountain area. The intrusion therefore probably occurred in Mesozoic time. These granitic masses are similar in composition and character to those of the main Coast Range belt and were perhaps intruded during the same period of igneous invasion. Their age therefore is probably late Jurassic or early Cretaceous.

DIKE ROCKS.

PEGMATITES AND APLITES.

Dike rocks composed essentially of alkali, feldspar, and quartz occur in the neighborhood of the large granitic masses. Some of these rocks are coarse grained, containing large crystals of feldspar, and are classed as pegmatites; others are fine grained and rather uniform in texture and are classed as aplites. Together they form in places a network of small dikes and stringers within a zone of fractured schists, though they are more prominent as separate dikes traversing the granitic intrusives. The rock in some dikes appears to be composed essentially of quartz with very little feldspar and epidote and some garnet, and also magnetite and pyrite. These dike rocks are readily recognized by their light color, granular texture, and mode of occurrence.

The modes of formation of the aplites and pegmatites associated with the batholithic intrusives have been discussed by many geologists, and the intimate relation in origin between these dikes and the quartz veins and ore deposits has been pointed out by Spurr,[1] Lindgren,[2] and Barrell.[3] The general belief is that the pegmatite dikes at least are produced by aqueo-

[1] Spurr, J. E., Geology of the Yukon gold district, Alaska: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, p. 311, 1898.
[2] Lindgren, Waldemar, The character and genesis of certain contact deposits: Am. Inst. Min. Eng. Trans., vol. 31, pp. 242-244, 1902.
[3] Barrell, Joseph, Geology of the Marysville mining district, Montana: U. S. Geol. Survey Prof. Paper 57, 1907.

igneous activity, through a process intermediate between injection of molten magma and precipitation from aqueous solutions.

The intimate association of the aplite and pegmatite dikes with the deposits in the contact zones and their relations to the ore deposits and the granitic intrusives are considered more fully under the heading "Genesis of the ores" (p. 102). The microscopic petrography of a specimen of the rock is described by Dr. H. E. Merwin as follows:

Specimen 622. Collected from a point on trail to Jumbo mine at an elevation of 700 feet. This rock is fine grained, almost white, and contains about 45 per cent each of orthoclase and plagioclase. The plagioclase varies in composition from Ab_4An_1 to Ab_2An_1. The rest of the rock mass is made up of 8 per cent of quartz and 2 per cent of hornblende, zircon, and other minerals. The rock, then, is an adamellite aplite.

PYROXENE-FELDSPAR DIKES.

Dikes or veins of rocks composed essentially of pyroxene and feldspar occur within the contact zones and branch out into the intrusive and intruded rocks. These rocks vary widely in composition, ranging from those containing 90 per cent of feldspar and 10 per cent of pyroxene to those containing 70 per cent of pyroxene and 30 per cent of feldspar. In some of them garnet and sulphide minerals occur both as primary mineral constituents and in cracks or veinlets as secondary minerals. The rocks have a medium to fine grained granular texture and are usually light to dark green in color, though where orthoclase dominates they are flesh-colored. These rocks cut the granitic intrusive rocks and were probably injected into fissures in the contact zone in a manner similar to the aplite dikes though at a somewhat later period. Their intersection by veinlets of garnet and the alteration of the feldspars in some of them to scapolite indicate that their formation antedates that of the ore deposits, though they may have been formed at about the same time, and their composition suggests that they were derived from the same underlying magma that produced the contact rock.

The microscopic petrography of the rock is described by Dr. H. E. Merwin as follows:

Specimen 11. Collected from 10-foot dike in contact zone one-half mile southwest of Copper Mountain at an elevation of 2,500 feet.

This rock occurs in small dikes or veins which are confined to the borders of the intrusive masses and cut both the intrusive rock and the contact rock. It also occurs in irregular masses at the margins of the granitic intrusives.

The rock is of fine-grained granitic texture, flesh-colored, and in the hand specimen shows patches of light-green pyroxene in a groundmass made up of irregular grains and plates of orthoclase. Under the microscope orthoclase and diopside are shown to be the chief constituents; albite, titanite, and apatite are present as accessories and compose about 1 per cent of the rock mass. The orthoclase constitutes about 90 per cent of the rock, and occurs in both anhedral grains and in subhedral plates showing Carlsbad twinning. The pyroxene is subhedral and is colorless to pale green. Optically, it is diopside with a probable slight mixture of ægirite in the greenish grains. Its distribution is somewhat irregular. This rock may be called a diopside orthoclasite.

An analysis of the rock made by Chase Palmer and calculations from the analysis by the methods of the quantitative system show the following chemical and mineralogic (normative) composition:

Chemical composition of diopside orthoclasite.

SiO_2	62.03	K_2O	12.38
Al_2O_3	16.39	H_2O-	.24
Fe_2O_3	.72	H_2O+	.61
FeO	.86	TiO_2	.53
MgO	1.60	P_2O_5	.13
CaO	3.60		
Na_2O	1.08		100.17

Mineral composition of diopside orthoclasite.

Quartz	1.26	Magnetite	0.93
Orthoclase	73.39	Apatite	.34
Albite	9.43	Ilmenite	1.06
Anorthite	3.06	(Water)	.85
Diopside	8.89		
Wollastonite	1.04		100.25

The notable characteristics of the rock are its high orthoclase and low quartz. The normative orthoclase is higher than for any rock in Washington's tables,[1] and the actual orthoclase (which includes the normative albite and anorthite in solid solution) is higher still. A quartz-orthoclasite listed on page 143 of Washington's tables contain about the same amount of normative orthoclase. The rock belongs in the rang nordmarkare of the quantitative system, but its high potash content places it in a hitherto unrepresented subrang—the perpotassic—which may properly be called hettose, from the occurrence of the rock on the shores of Hetta Inlet.

Specimen 615. Collected from 6-foot dike cutting diorite in long tunnel 500 feet from mouth of New York claim.

This is a greenish holocrystalline rock consisting of a light-colored pyroxene (about 70 per cent) and plagioclase feldspar which is largely altered to scapolite. Much of the scapolite is in individual crystals more than a hundred times as large as the feldspar crystals replaced, giving the rock a poikilitic appearance. Euhedral crystals of pyrite and much chalcopyrite and pyrrhotite are scattered through the rock. The last two minerals appear to have been introduced at the same time as garnet and epidote, which fill many joints in the rock. What appears to have been an earlier set of minute veins filled with feldspar are now parts of scapolite crystals. The pyroxene occurs mostly in small rounded grains, but also in larger, irregular crystals. This mineral is unaltered.

Specimen 623. Collected from 4-foot dike cutting diorite and contact rock just below open cut on New York claim.

A fine-grained rock which in the hand specimen is greenish with irregular bright pink blotches. Under the microscope the green color is found to be due to a pyroxene which occurs in rounded grains and irregular crystals having a very fresh appearance. The pink masses are altered feldspar. Phenocrysts of acid labradorite have been altered to very fine grained aggregates. The alteration has extended around the phenocrysts into the plagioclase of the groundmass, thus making the pink areas irregular. The predominant mineral of the aggregates, though not occurring in grains large enough for positive identification, is probably a light-colored mica. In the slide it resembles the scapolite of other altered rocks of the district, but it has positive elongation parallel to the cleavage. Examined in powdered form, its refractive indices were found to be 1.56 to 1.59. Other minerals in the alteration aggregates are calcite and a mineral having moderate to weak double refraction and refractive index of about 1.69—probably zoisite.

Specimen 658. Collected from dike on Jumbo No. 4 claim, upper surface workings.

A fine-grained granitic rock containing about 50 per cent each of basic plagioclase and a pale-green pyroxene. The minerals are very fresh, even where cut by numerous veins of garnet. A few grains of the pyroxene are altered to a more highly refracting mineral showing interference colors like zoisite. This alteration seems to have taken place before the garnet veins came in. These are sharply bounded by fracture surfaces.

PORPHYRIES.

Porphyritic dike rocks are common within the area and were observed principally along the shores and in the streams that traverse the schists and limestones (probably largely Carboniferous) as well as the later greenstones. They cut the granitic intrusives and the aplite dikes and are therefore of more recent intrusion. The porphyritic dikes are generally 5 to 50 feet

[1] Washington, H. S., Chemical analyses of igneous rocks published from 1884 to 1900, with a critical discussion of the character and use of analyses: U. S. Geol. Survey Prof. Paper 14, 1903.

wide but average about 12 feet in width. The rock consists of a finely crystalline groundmass with phenocrysts of basic plagioclase and hornblende.

The microscopic petrography of the rock is described by Dr. H. E. Merwin as follows:

Specimen 59. Collected from south shore of Hetta Inlet 1 mile west of Gould Island.

This is a light greenish-gray fine-grained porphyritic rock containing phenocrysts of plagioclase. In the thin section the plagioclase (acidic andesine) forms 75 per cent of the rock, a light-green slightly pleochroic hornblende, in irregular crystals and scattered grains, forms 15 to 20 per cent, and magnetite forms 5 to 10 per cent. Titanite, epidote, and calcite occur in very small amounts. The groundmass shows a decided parallel arrangement of the plagioclase crystals due to flow structure.

The rock is a diorite porphyry.

Specimen 104. Collected from a dike 30 feet wide near the ore deposit on a ridge on the west slope of Hetta Mountain.

This is a medium to fine grained porphyritic rock containing abundant plagioclase and scattered phenocrysts of hornblende. Under the microscope the phenocrysts of plagioclase, approximately andesine in formation, appear to be well-bounded crystals, zoned and twinned. The hornblende occurs in ragged prisms, shows pleochroism from light yellow to light green, and is partly chloritized. The groundmass is made up of a finely granular plagioclase that exhibits no distinct twinning or zoning but shows undular extinction. Magnetite, titanite, and apatite are accessory constituents.

The rock is a porphyry.

Specimen 73. Collected from dike 6 feet wide cutting schists on the west shore of Hetta Inlet opposite Jumbo Island.

This is a fine-grained porphyritic rock with long, slender phenocrysts of hornblende up to 2 centimeters in length, having a parallel arrangement, probably due to flowage in the magma before crystallization. Many of these crystals show effects of magmatic corrosion. The hornblende, which constitutes 35 per cent of the rock, is pleochroic, ranging from light yellow to dark yellow-green. A colorless pyroxene occurs in irregular grains in small amount—about 3 per cent. The feldspar (andesine to acidic labradorite) occurs in very small poikilitic crystals which are usually not twinned. Alteration to chlorite and calcite has begun. The feldspar, including a plagioclase of similar composition in the groundmass, constitutes 45 per cent of the rock mass. Magnetite is abundant, forming about 10 per cent of the rock.

The rock is a diorite porphyry or lamprophyre.

LAMPROPHYRE.

Dikes of lamprophyre, most of them 1 foot to 6 feet wide, cut the rocks near the granitic contacts. (See Pl. VI, *B*, p. 32.) They are generally much altered and in places are faulted, and no older intrusive rock was noted in the area. They are older than the ore deposits or the granitic intrusives. The dikes in the contact zone are broken and have been here and there much altered and in part replaced by minerals of the contact rock. The rock is black, fine grained, and of porphyritic texture, and contains phenocrysts of pyroxene, mostly uralitized. Plagioclase and uralite compose the groundmass. The accessory minerals are magnetite and titanite.

Dr. Merwin describes the microscopic structure of the rock as follows:

Specimen 651. Collected from open cut in gulch on Jumbo No. 4 claim, Copper Mountain.

This rock is greenish black, of aphanitic texture, and under the microscope shows about 70 per cent of amphibole, 20 per cent of altered plagioclase, 5 per cent of biotite, and some pyrite, titanite, and magnetite. It is traversed by veinlets that vary from mere threads to ribbons several inches wide, formed of garnet and diopside. The rock near these veinlets and at the contacts has assumed a lighter color, owing to the bleaching of the hornblende.

The rock is an altered lamprophyre.

Specimen 658. Collected from dike cutting limestone at mine workings in gulch on Jumbo No. 4 claim.

A fine-grained to porphyritic greenish-black rock containing altered labradorite (60 per cent) showing zonal structure. The groundmass contains also chlorite and magnetite and secondary veinlets of diopside and garnet. Near the contacts of the dike and adjacent to the veinlets the rock is altered to a lighter green.

The rock is an altered lamprophyre.

DIABASE.

Many dikes of diabase were noted along the shores of Hetta Inlet. They cut the greenstones and here and there the older schists and limestones. They are generally from 2 to 10 feet wide, and most of them strike northeastward across the stratification of the country rock. The diabase is essentially a plagioclase-augite rock of diabasic texture, dark-green color, and medium fine grain. In certain places coarse-grained dikes of this rock, the largest 50 feet wide, resemble gabbro, though they still retain a diabasic texture.

These diabase dikes are evidently younger than the granitic intrusives and the ore deposits, for they cut the contact deposits on the Green Monster claim, as well as those in the greenstone schists on the Corbin claim. They have no genetic relation to the ore deposits.

Dr. Merwin's descriptions follow.

Specimen 58. Collected from point 1½ miles north of Jumbo Landing, on east side of Hetta Inlet.

The rock is of porphyritic texture. Large crystals having the outlines of augite form the phenocrysts. This augite and that appearing in the groundmass are entirely uralitized. Feldspar occurs in small crystals. Very many slender prisms of apatite, included by the feldspar, and minute crystals of titanite are the principal accessory minerals. The rock contains 70 per cent of uralite, 25 per cent of labradorite, and 5 per cent of accessory minerals.

The rock is an altered diabase.

Specimen 48. Collected from 15-foot dike cutting schists on south shore of Hetta Inlet, 1 mile east of Gould Island.

This rock is medium to fine grained and of porphyritic texture. The phenocrysts are 4 to 7 millimeters in length and consist of plagioclase and hornblende. The plagioclase (acidic labradorite) is twinned after the Carlsbad and albite laws and makes up about half the volume of the rock. So much feldspar is inclosed on the irregular margins of the hornblende crystals as to give them a poikilitic appearance. The biotite, which constitutes about 5 per cent of the rock, occurs in very fine scales, scattered rather evenly. Magnetite and pyrite occur in small grains in the groundmass.

The rock is a diabase or, more specifically, a hornblende dolerite.

GEOLOGIC HISTORY.

The record of the periods of sedimentary deposition and igneous intrusion represented in the Copper Mountain area is defined only by structural relations, not by paleontologic evidence. The oldest sedimentary strata are the schists and limestones, which are probably largely of Carboniferous age, an inference based on their marked similarity to the metamorphic schists of the mainland belt, where included limestone beds contain Carboniferous fossils, though they probably include some strata of Mesozoic age. This metamorphic series is made up of a great thickness of bedded rocks, originally argillaceous, calcareous, and siliceous shales and sandstones, and may include several conformable formations. More recent in age are the greenstones, which overlie the schists and limestones with apparent conformity. They are characterized by their content of volcanic material, indicating an extensive period of volcanic eruption, which assumed the form of tuffaceous outbursts rather than that of lava flows. Evidence from adjacent areas indicates that these rocks were deposited in Mesozoic time. Later all these bedded rocks were subjected to mountain-building forces, which induced metamorphism and upturned the stratified rocks within the area. During this period basaltic dikes or lamprophyres were injected along fracture planes in the rocks and were also subjected to faulting and flexuring due to the mountain-building forces.

The most important geologic event in the region was the granitic intrusion, which continued during a long period and by which a large quantity of igneous material was carried from an underlying magma into the overlying sedimentary rocks. The main granitic intrusion is regarded as Mesozoic, probably late Jurassic or early Cretaceous, and conforms in age to the Coast Range intrusions. The intrusion of the granitic masses was followed by the injection of pegmatite and aplite dikes, which are regarded as differentiation products of the granitic magmas.

The next important event was the deposition of ores at the contacts of the intrusive masses—an event that closely followed the injection of the pegmatite and aplite dikes. The ore deposits were accompanied by large masses of garnet-epidote-diopside rock, which, like the ore deposits, are believed to have been derived from the underlying granitic magma. The most recent rocks in the area are the porphyritic and basalt dikes, which are fairly abundant. These intrusions probably occurred in Mesozoic time. The record of the more recent geologic periods, though not found in the rock formations, is represented in the present topographic features, which have already been described.

COPPER ORES OF THE COPPER MOUNTAIN AREA.

GENERAL CHARACTER.

The Copper Mountain area presents exceptional opportunities for a study of the relations between the igneous intrusives, the ore deposits, and the occurrence of minerals attributable to metamorphic actions, but as only a few months were spent in the field, and as an exhaustive study of the minerals and rock specimens collected has not been made, the problems presented can be only briefly considered.

In order not to confuse observed facts with hypotheses regarding ore genesis, metamorphism, and like phenomena, only the observed facts will be stated here and the more theoretical questions will be discussed under the heading "Genesis of the ores" (p. 102). The principal metal in all the ore deposits in the area is copper, gold and silver appearing in minor quantities. Considerable bodies of magnetite are associated with some of the copper ores, but these have not yet been mined except for their copper content. Zinc and lead are present in some of the ores but not in commercial amounts. The deposits consist mostly of primary minerals, the ores not having been enriched by the action of surface waters.

GEOGRAPHIC AND GEOLOGIC DISTRIBUTION.

The distribution of the ore deposits is clearly shown on the geologic map of the Copper Mountain area (Pl. V, p. 30). This map indicates the location of ore bodies on which some development work has been done and which are described under the heading "Mining in the Copper Mountain area" (p. 53).

The relation of these deposits to the geology, and especially to the granitic intrusives, is best seen by reference to the map. A striking fact is that most of the deposits are at the contacts of the granitic intrusives with the limestones and schists, especially in the places where the line of contact forms strong reentrants. Other deposits occur in the greenstones at a considerable distance from the intrusive contacts.

TYPES OF ORE DEPOSITS.

The following three types of ore deposits have been recognized in the Copper Mountain area:

Contact deposits, occurring at the contact of the granitic rocks and the schists and limestones; containing chalcopyrite associated with pyrite and magnetite or pyrrhotite in a gangue of garnet, pyroxene, amphibole, epidote, and other metamorphic minerals; also calcite and some quartz.

Vein deposits, occupying fissures or shear zones in the greenstones and containing shoots of massive sulphide ore composed of chalcopyrite and pyrite, with some sphalerite, in a quartz-calcite and chlorite gangue.

Disseminated deposits, consisting of mineralized schistose beds in the older schists. Chalcopyrite and pyrite are finely disseminated through these beds and are accompanied by quartz and calcite veinlets.

The contact deposits are the most important commercially and of greatest interest geologically and are therefore considered at length in this report. The vein deposits are less important, though at two mines they have been developed to a considerable extent. The disseminated deposits are at present of little importance and have been only slightly developed, for their low metal content prevents their exploitation.

CONTACT DEPOSITS.

THE CONTACT ZONE.

The contact deposits occur within the contact rock that occupies a zone surrounding the granitic intrusive masses. This contact rock is made up of various combinations of minerals, its principal components being garnet, amphibole, pyroxene, epidote, and calcite, which occur together in separate crystalline groups or more often as a felsite-like mass. The contact rock occurs irregularly around the contact zone; in some places it is entirely lacking and in others it has a surface width of several hundred feet. Its surface width at many points is much greater than its actual width, especially on hillsides where the dip of the intrusive rock surface is only slightly steeper than the slope. Its usual width, however, ranges from 25 to 250 feet. At certain localities the intrusive and intruded rocks are in direct contact with each other, the minerals composing the contact rock being notably absent.

In some places dikes or veins of the contact rock branch out into the limestones and schists and occupy fissures in the granitic intrusive. Few of these veins are more than 1,000 feet long. Large areas of the contact rock occur just within the granitic intrusive and on the surface appear to be surrounded by the granitic rock. These areas may represent wide fractures within the intrusive which have been filled with the contact rock, or they may be masses of the intruded rocks which have been replaced by the contact rock.

THE ORE IN THE CONTACT ZONE.

Types of contact deposits.—The ore within the contact zone occurs in irregular masses that range in diameter from 10 to 100 feet. These masses generally occur on one or the other side of the contact zone; they are rarely found in the center.

The contact deposits may be divided into two classes, according to their mineral composition. In certain deposits chalcopyrite ore is associated with masses of magnetite and these are distinguished as the chalcopyrite-magnetite type. In other deposits chalcopyrite is associated with pyrrhotite and these are distinguished as the chalcopyrite-pyrrhotite type.

Chalcopyrite-magnetite type.—The chalcopyrite in deposits of the chalcopyrite-magnetite type is usually disseminated and seldom in rich masses. The gangue minerals are garnet, amphibole, and pyroxene, and the deposits are compact and finely crystallized. Deposits of this type were noted only between the granitic intrusive and the contact rock, as on the north side of Jumbo Basin, where erosion has removed the overlying contact rock and the magnetite deposit exposed resembles a shell or coating on the surface of the granitic intrusive. This deposit is from 5 to 15 feet thick and over 100 feet wide. At its contact with the granitic rock, which is the footwall, the ore, with the contact minerals, grades into the intrusive mass, the minerals of which are replaced by garnet, epidote, calcite, etc. This zone of gradual replacement between the contact rock and the intrusive is often many feet wide. On the hanging-wall side is the contact rock, which is overlain by metamorphic schists, and here also there is no line of demarcation between the two rocks but a gradual change due to replacement of the schists by the contact minerals.

Chalcopyrite-pyrrhotite type.—In this type chalcopyrite and pyrrhotite, the two principal sulphide minerals, occur associated together and also in separate masses. The gangue minerals are garnet, diopside, epidote, calcite, and rarely quartz. (See Pl. VIII.) Pyrite is present

but no magnetite. As a rule these minerals are coarsely crystallized, calcite filling the interstices and small crystal druses being common. These features of crystal occurrence are more clearly evident in rock adjacent to the ore bodies and help to indicate the location of the masses of sulphide ore. Farther away from the ore bodies the contact rock is more compact and even felsitic in aspect. These features of the ore deposits are clearly shown in the mine tunnels on Jumbo No. 4 claim at the head of Jumbo Basin. Deposits of the chalcopyrite-pyrrhotite type are most likely to be found where limestone occurs at the contact or on the contact rock adjacent to the limestone. They are also found at the contacts of the granitic rocks with the contact rock and in masses of contact rock that lie within the granitic intrusives. One of the most important masses lies within a vein of contact rock that branches out into the limestone beds, away from the contact zone.

Relation of intruded rocks to contact deposits.—The influence of the different rock strata at the contacts of the intrusive masses on the nature of the contact deposits is noteworthy, as the character of the intruded strata determines to some extent the location of the ore masses. However, these rock beds have not entered into nor do they determine in large measure the composition of the contact rock which incloses the deposits, as has been pointed out in reports on other districts where contact deposits occur. Where limestone forms the wall rock the effect has been to limit the ore deposits and the contact rock rather abruptly; in other words, the minerals of the contact deposits do not penetrate the limestone wall. The limestones at these points show no bedding planes, are very pure in composition, are recrystallized to a fine white marble, and were apparently impervious to the mineralizing solutions. Large rounded detached masses of the limestone walls occur within the contact rock, and the edges of these masses and those of the limestone walls indicate that this rock has been dissolved or eaten away by the mineral solutions that deposited the ores and the contact rock. As many of the richer ore masses occur where the limestone is present, the limestone may have assisted in precipitating the sulphide minerals. This question is discussed under the heading "Genesis of the ores" (p. 102).

Where the schistose rocks form the walls of the contact deposits the mineralization is less concentrated, the contact rock shows less tendency to crystallize, and the minerals show less tendency to segregate. The sulphide ores are more disseminated in the contact rock, and the contact minerals, including the sulphides, penetrate the schists for some distance from the contact. Angular fragments of the schistose rocks are in places included in the contact rock, and veins of the latter extend along fissures and between the schist strata for some distance away from the contact zone. The schists that show this replacement by the minerals composing the contact rock are essentially calcareous, whereas the more siliceous rocks apparently suffered little change during the mineralization.

Location of minable ore.—The productive ore masses found in the contact zone are confined chiefly to Jumbo Basin and the Copper Mountain ridge just above Jumbo Basin. (See Pl. III, *B*, p. 28.) These deposits are of the chalcopyrite-pyrrhotite type. Large deposits of the chalcopyrite-magnetite type occur on the north side of the Jumbo Basin and are said to contain sufficient copper to make them minable, but they are far away from transportation lines.

Other ore masses have been prospected at many points around the granitic intrusive masses, but most of them are not convenient to lines of transportation and it has been difficult to do development work on them, so that on most of the locations little has been done but the annual assessment work.

VEIN DEPOSITS.

Most of the vein deposits are in the schists, with which they generally coincide in strike and dip. These veins are persistent in length and depth, and the ore in them occurs in shoots of massive sulphides, essentially chalcopyrite, pyrite, and some sphalerite, associated with calcite, quartz, and chlorite. These shoots are 1 foot to 4 feet wide, 20 to 80 feet long, and at one locality have been developed to a depth of more than 100 feet. Those parts of the veins that carry no ore are well marked by gouge containing pyrite and veinlets of quartz and calcite.

The altered schist near the veins is pale green to white, the color of the rock grading away from the veins into the general dark-green color of the unaltered schist. Veins of this type have been developed at the Corbin and Red Wing mines, both situated near sea level along the east shore of Hetta Inlet. These deposits will be described in detail under the heading "Mining in the Copper Mountain area" (p. 53).

DISSEMINATED DEPOSITS.

At a few points in the Copper Mountain area mineralized schists carrying small amounts of copper and gold have been found, and on certain of these deposits small developments have been made. Some of these deposits extend for long distances and range in width from 5 to 25 feet. They are intercalated in the older schists and some of them are more or less fissured, the fissures carrying quartz and calcite. The principal deposits of this type occur in the lower part of Jumbo Basin at an elevation of about 300 feet. Because of their low copper content they have not been extensively explored and have not yet become productive.

MINERALS OF THE DEPOSITS.[1]

SCOPE OF THE DISCUSSION.

The minerals composing the ore deposits in the Copper Mountain area are doubtless of less interest to the miner than the ore bodies themselves, but the mineralogy of the ores is important to the geologist and may assist him materially in determining the conditions under which the deposits were formed. Here, however, only brief mention will be made of the ore and gangue minerals of the deposits. Detailed descriptions of the essential features of each mineral may be found in any textbook on mineralogy. The primary ore minerals are described first, then the secondary ore minerals, and then the gangue minerals and other minerals in the contact zones.

PRIMARY ORE MINERALS.

Chalcopyrite.—The principal ore in the Copper Mountain district is chalcopyrite, the sulphide of copper and iron, which occurs in the contact deposits chiefly in masses more or less mixed with pyrite and pyrrhotite (see Pl. VIII, *E*), in the vein deposits in rich though relatively small ore shoots, and in the disseminated deposits in finely scattered particles, generally not in amount sufficient to form an ore. Chalcopyrite is readily distinguished from the iron-sulphide minerals by its brass-yellow color and by the fact that it is softer and powders readily under the knife blade. In the contact deposits it is associated with pyrite, hematite, and, more rarely, molybdenite, the gangue minerals being principally garnet, quartz, calcite, pyroxene, amphibole, and epidote; in the vein deposits it is accompanied by sphalerite or galena. At the Jumbo mine chalcopyrite and garnet fill spaces between interlacing crystals of scapolite. In the contact deposits chalcopyrite is in places well crystallized in druses, though in the other deposits no crystals were observed. The other sulphides of copper—namely, bornite and chalcocite—were not noted in the district.

Pyrite.—Pyrite, a sulphide of iron, occurs in all the ore deposits and is scattered through the metamorphic rocks of the region and finely disseminated in the igneous rocks. It has not been found in masses large enough to make it valuable as an ore of sulphur. The copper ores contain large percentages of pyrite, which carries gold in amounts ranging from $1 to $2 to the ton. The pyrite disseminated in the schists also contains gold.

Pyrrhotite.—The occurrence of pyrrhotite is similar to that of pyrite, though it is less widely distributed. It is a sulphide of iron containing less sulphur than pyrite and is readily distinguished by its darker bronzelike color and its magnetic properties. It occurs in large masses in the contact deposits, but was not noted in the vein deposits. (See Pl. VIII.)

Pyrrhotite ores containing sufficient nickel to make a nickel ore occur at Sudbury, Canada, and at several foreign localities, notably at Kongsberg, Norway. Because of this association

[1] The writer is indebted to Dr. H. E. Merwin, of the Geophysical Laboratory of the Carnegie Institution of Washington, for a detailed study of the minerals collected from this region. The results of Dr. Merwin's investigations are given in the mineral descriptions.

PLATE VIII.

A. Ore containing irregular groups of pyrite crystals and chalcopyrite in a gangue of calcite, diopside, and garnet. Specimen taken near granite contact, Jumbo claim No. 4. *c*, Calcite; *ch*, chalcopyrite; *dc*, diopside, calcite; *g*, essentially garnet; *p*, pyrite.

B. Scapolite. This mineral occurs in masses of radiating crystals in druses. Specimen from upper workings on Jumbo claim No. 4.

C. Specimen showing contact of limestone with contact rock. At the contact and adjacent to it in the limestone a very light colored amphibole has been developed. The main mass of dark rock is diopside and calcite, but in the immediate vicinity of the ore and to a less degree in other parts of the mass a dark amphibole appears. The limestone is rather pure. *c*, Calcite; *ch*, chalcopyrite; *ag*, calcite amphibolite, garnet; *dg*, diopside, garnet.

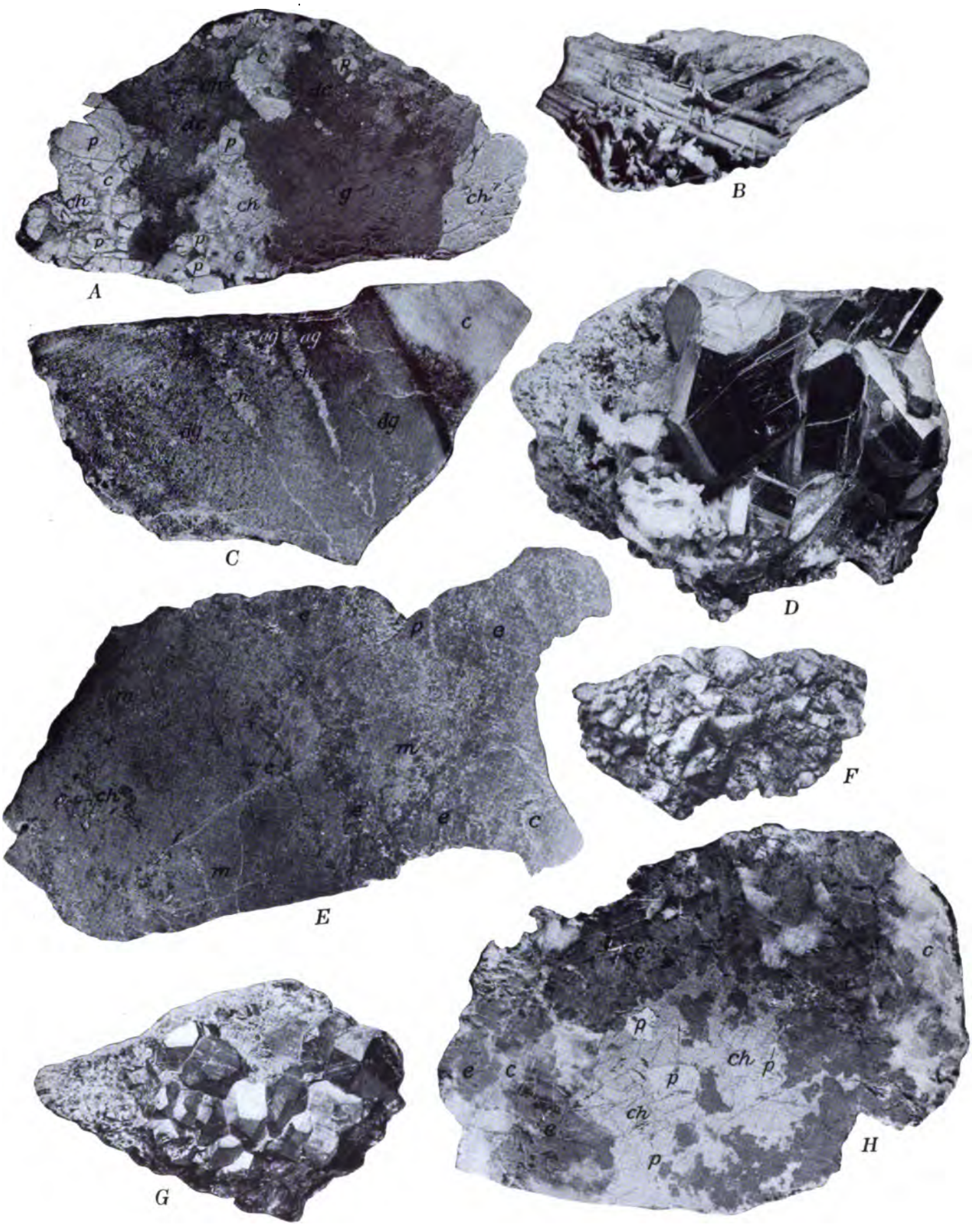
D. Group of epidote crystals and cluster of quartz crystals on contact rock. Specimen from west slope of Green Monster Mountain near summit.

E. Metallic minerals (magnetite, pyrite, and chalcopyrite) associated with minerals of the contact rock, principally epidote and calcite. Specimen from Jumbo claim No. 1. *c*, Calcite; *ch*, chalcopyrite; *e*, epidote; *m*, magnetite; *p*, pyrite.

F. Adularia showing prismatic crystals with slightly curved faces. Specimen from north side of Green Monster Mountain near summit.

G. Garnet. These crystals are smaller and of a more uniform color than the garnet which predominates in the contact deposits. From New York claim, Copper Mountain group.

H. Crystals of pyrite inclosed in pyrrhotite. The gangue consists almost entirely of calcite, which is tinged greenish in places by inclusions of minute diopside crystals. From Jumbo claim No. 4 near limestone contact. *c*, Calcite; *ch*, chalcopyrite; *e*, epidote; *p*, pyrite.



ROCKS AND MINERALS FROM COPPER MOUNTAIN AREA.

and because masses of this mineral at one locality were reported to contain large amounts of cobalt, samples of nearly pure pyrrhotite were taken at two different localities and submitted for determination of their content of nickel, cobalt, platinum, and gold, with the following results:

Assays for rare metals in pyrrhotite ore.

[Assays made by George Steiger, United States Geological Survey.]

	Nickel.	Cobalt.	Platinum.	Gold.
	Per cent.			
No. 5. Sultana claim, north side of Hetta Inlet, Ketchikan district, Alaska	0.1–0.2	Trace.	None.	None.
No. 6. Iron-Crown claim, Copper Mountain, Ketchikan district, Alaska	.1– .2	Trace.	None.	None.

Sphalerite.—The mineral commonly called zinc blende, the sulphide of zinc (sphalerite), containing 67 per cent zinc, having generally a dark color and a semimetallic luster and distinguished by its light-brown powder, is found in the vein deposits associated with chalcopyrite and galena, quartz and calcite being the gangue minerals. It is not known to occur in quantities sufficiently large to make a zinc ore.

Galena.—Galena, the sulphide of lead, occurs in small amounts in vein deposits on Gould Island, associated with chalcopyrite and sphalerite, with calcite and quartz as gangue minerals.

Molybdenite.—The rare mineral molybdenite, the sulphide of molybdenum, occurs in the contact deposits, usually in small flakes in the contact rock or in the altered granitic rock near these deposits. At the Jumbo No. 4 claim it is associated with garnet, calcite, diopside, and chalcopyrite. It is a soft, flaky mineral with metallic luster resembling graphite but having a bluer tinge. It is not found in the Copper Mountain region in commercial quantities. (See Pl. VII, *A*.)

Magnetite.—Magnetite, the magnetic oxide of iron, occurs in large masses at the intrusive contacts, associated with the copper ores. Such masses are common in Jumbo Basin, where they have been largely developed. (See Pl. VIII, *E*.)

Minute grains and octahedral crystals of magnetite occur with the ferromagnesian silicates and in the groundmass of the greenstone schists and some of the intrusive rocks. Magnetite was also observed in certain pegmatite or aplite dikes and in quartz veins, with calcite, pyrite, and chalcopyrite.

The presence of chalcopyrite in these magnetite masses makes them important copper-bearing deposits and their high iron content gives them value to the smelters as a flux in the reduction of copper.

The occurrence of the magnetite in association with chalcopyrite, pyrrhotite, and pyrite in the contact deposits shows that it was deposited under conditions similar to those under which these sulphides were formed. In the intrusives, on the other hand, magnetite is apparently an original constituent.

Specularite.—Nearly all the contact deposits contain small amounts of specularite or micaceous hematite, an anhydrous oxide of iron. Its association indicates that it was deposited at the same time as the copper ores and under similar conditions. Flat crystals of specularite one-half inch across, showing numerous rhombohedral faces around the edges, were found.

SECONDARY ORE MINERALS.

Limonite.—The hydrous oxide of iron, limonite, is found principally at the surface outcrops of the ore deposits, having been formed largely from the decomposition of the iron sulphides. It occurs principally in association with the copper carbonate ores on the Copper Mountain ridge, where it extends to a considerable depth below the surface. In general these oxidized or secondary ores form only a shallow capping on the sulphide ore deposits.

Malachite.—The green mineral malachite, the basic carbonate of copper, is found in small amounts at the outcrops of the copper deposits, usually where limestone forms the inclosing rock. It occurs principally in small masses in a garnetiferous and limestone gangue on Copper Moun-

tain, where surface alteration has been extensive. It generally forms narrow seams or veinlets and incrustation or coating on the sulphide ores and is associated with limonite, chrysocolla, and small amounts of cuprite. Its high copper content and the facility with which it may be smelted make it a most desirable copper ore, but no large deposits of it have been found in the district.

Azurite.—Azurite, like malachite, is a carbonate of copper, but may be distinguished by its deep-blue color. It was observed in small amounts only and invariably in association with malachite as a surficial alteration product of the sulphide copper ores.

Chrysocolla.—The hydrous silicate of copper, chrysocolla, like malachite and azurite, has been found in notable quantities only at the Copper Mountain mine, where it is apparently confined to the surface workings and is of minor importance.

Cuprite.—Cuprite, a red oxide of copper resulting from the oxidation of the sulphide ores, occurs in small amounts at the surface workings of the Copper Mountain mine.

Copper.—Native copper was observed at the Jumbo Basin mines on Copper Mountain and at the Houghton group. It occurs as thin flakes in cracks or gouge seams at the outcrops of the ore deposits. It is probably the result of deoxidation of cuprite and is therefore secondary.

GANGUE MINERALS.

Garnet.—Garnet is the principal gangue mineral of the contact deposits and is confined chiefly to the intrusive contacts. Though it commonly occurs in massive form, resembling a felsitic rock, it appears also in crystal aggregates associated with epidote, quartz, and other silicates. (See Pl. VIII, *G.*) The garnet found is mostly of the variety andradite, but includes some grossularite. The separate crystals are principally dodecahedrons with trapezohedral faces slightly developed. In cross section they show concentric structure resembling banded agate, being made up of yellow to pale-green and red bands which represent slight changes in composition occurring during the growth of the crystals. Partings parallel to the dodecahedral faces between zones of different colors indicate an interruption in growth, and some of the partings contain thin layers of calcite. (See Pl. VIII, *G.*) The crystals range in size from a few millimeters to 5 centimeters and many of them are twinned. In color the garnets differ greatly, presenting several shades of green, yellow, and brown. The crystal faces show subadamantine luster, though the masses have a rather greasy luster. To determine the variety of this massive garnet samples were submitted for analysis. The results of these analyses and of analyses of garnet from other localities are presented in the following table:

Analyses of garnet occurring in contact deposits.

	1	2	3	4	5	6
SiO_2	35.18	36.26	37.79	37.15	35.5	40.0
Al_2O_3	5.15	.78	11.97	6.98	.....	22.7
Fe_2O_3	25.05	32.43	15.77	19.40	31.5	.....
FeO	.40	.32	1.31	.....	.....	.....
MgO	.09	None.	.37	.....	.....	.....
CaO	33.36	29.67	32.57	32.44	33	37.3
H_2O	.42	.57	.09	.....	.....	.....
TiO_2	None.	None.	.....	.....	.....	.....
$CaCO_3$	.....	None.	.....	4.20	.....	.....
P_2O_5	.....	.06	.....	.....	.....	.....
MnO	.....	.27	.31	.....	.....	.....
	99.65	99.67	100.18	100.60	100	100

1. Garnet rock, Jumbo mine, Prince of Wales Island, Alaska. Analyst, W. T. Schaller.
2. Garnet, Morenci, Ariz., U. S. Geol. Survey Prof. Paper 43, p. 134. Analyst, George Steiger.
3. Massive brown garnet, White Knob, Idaho, Econ. Geology, vol. 2, No. 1, p. 7.
4. Garnet, San Jose, Mexico., Am. Inst. Min. Eng. Trans., vol. 36, p. 92.
5. Typical composition of andradite.
6. Typical composition of grossularite.

The above analyses show that the larger percentage of the garnet associated with contact deposits is andradite and not grossularite.

The masses of garnet are confined principally to the contacts of limestone of nearly pure calcium carbonate, with igneous rocks, suggesting that a vast amount of foreign material has

been introduced along the intrusive contacts. Where the intrusives invade a quartzite country rock the garnet forms bands in the siliceous beds, many of the bands extending thousands of feet from the contact. At Copper Mountain the garnet forms a massive belt, 25 to 150 feet wide, between the intrusive diorite and the limestone country rock and occurs in veins crosscutting the limestone beds and penetrating the intrusive rock. The belt includes small masses of chalcopyrite, magnetite, and pyrrhotite, which constitute the copper ores.

Besides occurring disseminated in the contact deposits and in veins, garnet is a primary mineral in some of the pegmatitic phases of the diorite, where it has invariably been observed to be isotropic in thin sections. In its other occurrences it is more or less doubly refracting.

Epidote.—Epidote, a calcium-iron-aluminum silicate, occurs principally as a gangue mineral in the contact deposits, in places forming large crystal aggregates with garnet quartz and calcite. (See Pl. VIII, *D.*) These crystals are large and brilliant, being usually dark green with light-green reflections. Many of them are twinned, showing striated faces, and in certain instances are truncated at both ends with numerous faces. The most perfect of these crystals were found on the Green Monster Mountain on the east side of the Copper Mountain intrusive mass. Specimens of these epidote crystals were described as follows by Dr. Charles Palache,[1] of the Harvard Mineralogical Laboratory:

> The specimens at hand consist of several loose and a magnificent cluster of large crystals implanted on massive epidote. The only associated mineral is quartz in small clear crystals of later formation than the epidote.
>
> The epidote is very dark green to greenish black in color, but oil-green and translucent in thin crystals or where bruised or cracked. The larger crystals are in the form of nearly square tables, which measure as much as 5.5 centimeters each way and 3 centimeters in thickness. In the smaller crystals the tabular habit is less pronounced, and the mineral sometimes assumes the ordinary prismatic habit parallel to the *b* axis. The crystals are not infrequently doubly terminated. In the large group to which reference was made about 20 of the tabular crystals are found on a surface measuring about 15 by 20 centimeters, several of the crystals being over 3 centimeters on an edge, and attached by an edge in such fashion as to present an appearance altogether foreign to epidote. The crystals are frequently twinned according to the ordinary law for epidote, the twinning plane being the orthopinacoid.

To this Dr. Palache adds a list of crystallographic forms determined on the crystals and illustrates these by drawings. In conclusion he states that the Alaska epidote ranks among the finest occurrences of American crystallized minerals and is surpassed in the size, beauty, and complexity of its crystals only by the epidote from Knappenwand, in the Tyrol.

Quartz.—The mineral quartz (silicon dioxide), which is easily distinguished by its glassy appearance, is not so abundant in this district as in most mineralized regions. In the contact deposits it occurs only in small amounts and is generally well crystallized and associated with crystals of garnet and epidote. (See Pl. VIII, *D.*) Many of the crystals are doubly terminated and some are very large, the largest noted being 10 centimeters long. The quartz is usually superposed on the garnet and epidote crystals and also surrounds the ore minerals, thus indicating that it was the last mineral to form.

In the vein deposits it is associated with calcite, both minerals occurring with the ore or in veinlets that intersect the ore veins.

In the Jumbo mine a cleavable variety of quartz, containing numerous minute needles of hornblende, is associated with chalcedony.

Calcite.—Calcium carbonate (calcite), commonly known as carbonate of lime, is of widespread occurrence. It is readily recognized by its perfect cleavage and its softness. Calcite is particularly prominent in the contact deposits and also occurs in the vein deposits. Where it is associated with garnet and epidote it is usually of later formation and in many places fills the interstices between crystals of these minerals. (See Pl. IX, *A*, *B.*)

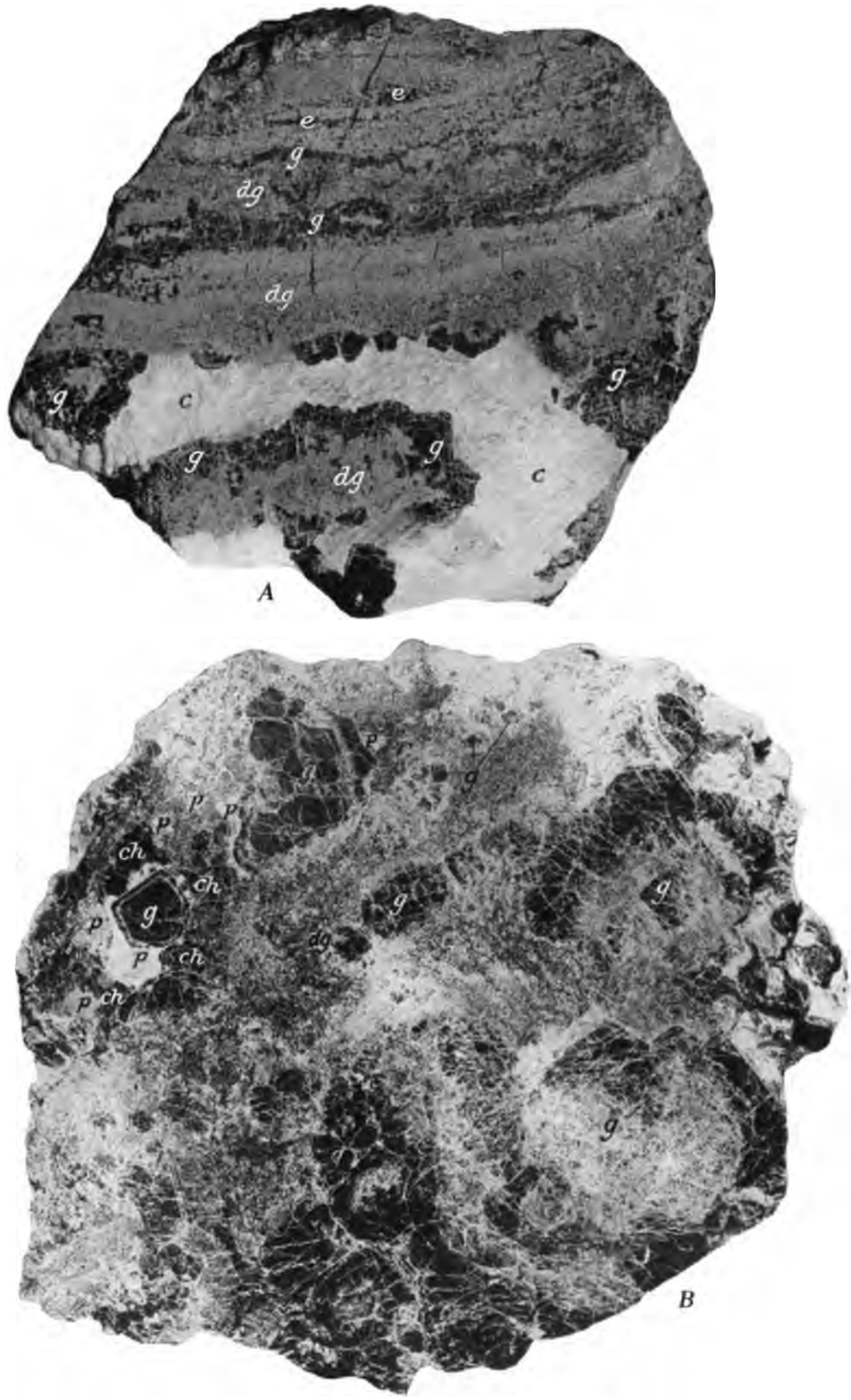
Diopside.—Diopside, a calcium-magnesium pyroxene, is a prominent gangue mineral of the contact deposits and is one of the principal constituents of the contact rock. In appearance it resembles epidote, for which it is often mistaken. Its color ranges from pale to deep green and it is generally scattered through the rock in minute crystals and grains, or it forms aggregates of needle-shaped crystals in veinlets and immediately at the borders of the contact rock. (See Pl. VII, *C.*)

[1] Am. Acad. Arts and Sci. Proc., vol. 37, No. 19, pp. 531–535, March, 1902.

PLATE IX.

A. Massive contact rock from contact zone on Jumbo claim No. 4. In the groundmass of garnet-diopside and calcite are large, irregular crystals of garnet, which show marked zonal structure. This specimen contains some pyrite and pyrrhotite. *c*, Calcite; *e*, epidote; *g*, garnet; *dg*, calcite, diopside, garnet.

B. Contact rock showing vein structure. This rock is made up essentially of garnet, diopside, and some calcite and is traversed by veinlets bordered with garnet crystals and filled with calcite, which was introduced subsequent to the formation of the garnet. *g*, Garnet showing zonal structure; *p*, pyrite; *ch*, chalcopyrite; *dg*, calcite, diopside, garnet.



CONTACT ROCKS FROM COPPER MOUNTAIN AREA.

Scapolite.—Scapolite, a calcium-aluminum silicate containing sodium and chlorine, occurs in veins in the vicinity of the ore deposits in prismatic crystals 1 inch or 2 inches in length, with rough, uneven faces, and varies from white to gray in color. It also replaces feldspar in the diorite near certain contacts. It was found only in the vicinity of the Copper Mountain deposits and is not common. (See Pls. VII, *A*, and VIII, *B*.)

Amphibole.—The hornblende variety of amphibole, a calcium-magnesium-iron silicate, is a common but not abundant gangue mineral in some of the copper contact deposits. At the Jumbo No. 1 mine it forms clusters of crystals in the magnetite ore. It is also present in the older schists which have been altered by the contact rock. (See Tremolite, below.)

Wollastonite.—The metasilicate of calcium, wollastonite, forms radiating clusters of crystals in the garnet and diopside contact rock. It also occurs in finely radiating crystals in the limestone and quartzites and in the diorite a short distance from the intrusive contact. It belongs with the minerals of the contact deposits, but its occurrence away from the contacts suggests that the heat required for its formation was not so great as that required to produce the garnet and diopside, which occur at the contacts.

Orthoclase.—Orthoclase is intimately associated with diopside, garnet, and calcite (see Pl. X, *C*); it appears both in compact masses that show no cleavage and in cleavable grains. Its occurrence in grains, however, is rare. The variety adularia occurs in druses at the Jumbo mine in well-formed crystals nearly a centimeter long. Quartz and biotite crystals incrust much of the adularia. (See Pl. VIII, *F*.)

Biotite.—Biotite occurs as a later mineral in the veins with adularia at the Jumbo mine.

Dolomite.—Cavities in the contact rock have furnished a few small specimens of dolomite in rhombohedral crystals.

Spinel.—Small octahedral crystals of the dark-green spinel, pleonast, were observed accompanying the clear diopside in the Green Monster mine.

Serpentine.—Serpentine appears in two very different forms—(1) as irregular yellowish, slickensided masses in the dolomitic limestone, and (2) as small, globular, radial-fibrous aggregates evenly distributed through the limestone. The aggregates are almost microscopic in size and are nearly white. One specimen of limestone containing about 30 per cent of these spherules could not be distinguished in color from a pure limestone.

Tremolite.—Tremolite occurs as loose felty masses of slender white fibers in the limestone at the Green Monster claim. It was also noted at other localities, but only in small quantities.

Talc.—Talc was one of the last minerals to form in some of the veins and is found in druses of quartz; also along slipping planes in the ore bodies.

Zoisite.—Zoisite is usually associated with epidote, the two minerals in some places growing side by side apparently contemporaneously. Clusters of pink zoisite were also noted in veins of diopside.

Clinochlore.—Druses probably containing clinochlore, a soft greenish-blue micaceous mineral, were observed in the ore masses of the Jumbo No. 4 claim. This mineral is a hydrous silicate of magnesium and aluminum and is of secondary origin.

Zeolites.—Three varieties of zeolites were collected in the Copper Mountain area, namely, stilbite, chabazite, and heulandite, all hydrosilicates of aluminum with calcium and sodium. They were found in cavities formed in the tongue of contact rock just south of Summit Lake. They are secondary minerals occurring as druses with garnet and epidote crystals. The stilbite (see Pl. X, *A*) occurs in characteristic sheaf-like aggregates and the chabazite in nearly cubic rhombohedrons about a quarter of an inch in diameter. Heulandite was also noted in the form of flakes upon the stilbite crystals.

MINING IN THE COPPER MOUNTAIN AREA.

GENERAL CONDITIONS.

Copper is now (1908) being produced by only one large mine in the Copper Mountain area—the Jumbo mine, belonging to the Alaska Industrial Co. In past years the mines of the

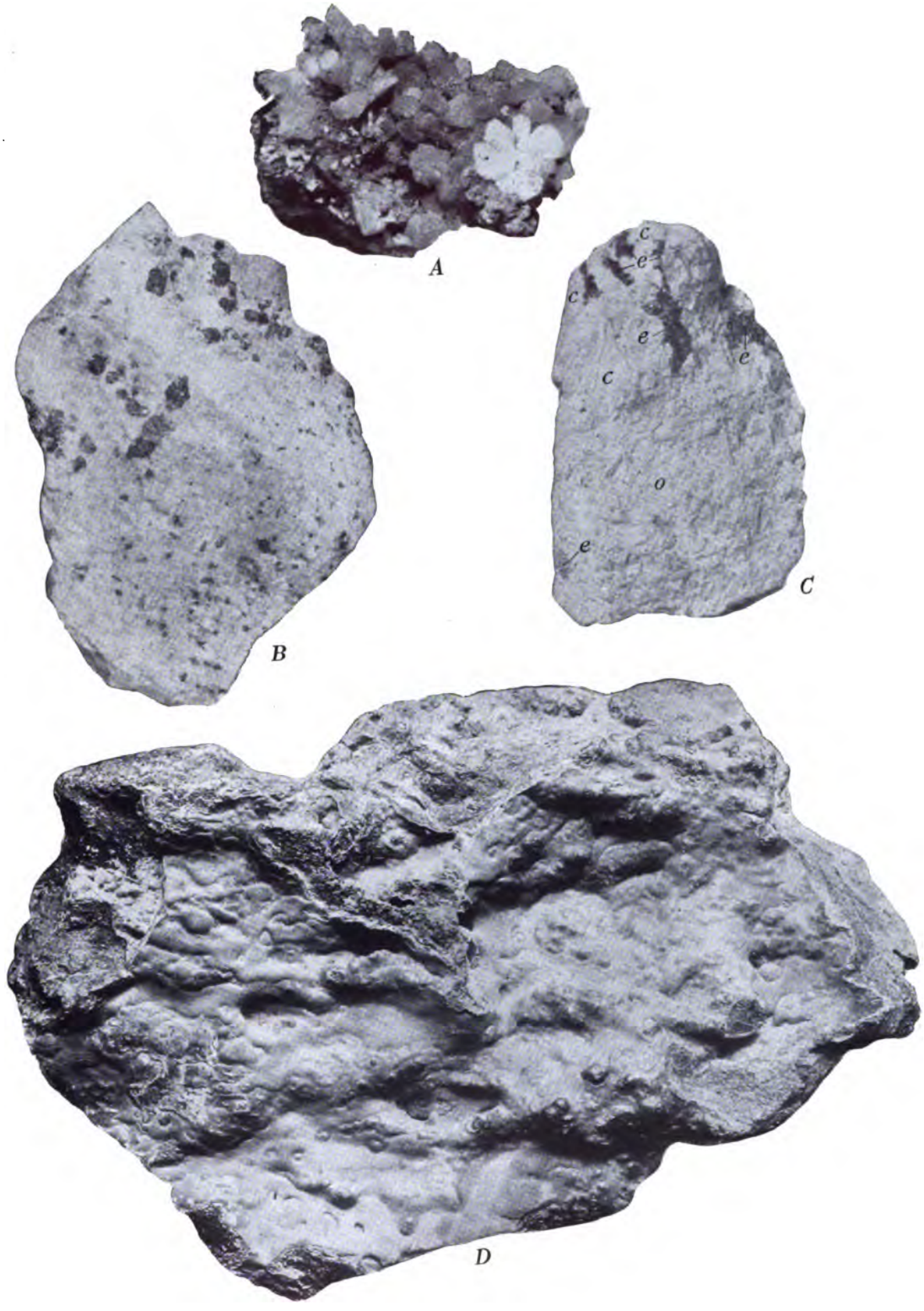
PLATE X.

A. Groups of crystals of stilbite, which occurs with chabasite in druses in the garnet-diopside-calcite contact rock. Specimen from tongue of contact rock south of Summit Lake.

B. Specimen from pegmatite dike in granite on Jumbo claim No. 4, showing quartz and feldspar and small disseminated crystals of garnet.

C. Orthoclase with epidote and some calcite from veinlet in contact rock on New York claim, Copper Mountain group. *c*, Calcite; *e*, epidote; *o*, orthoclase.

D. Malachite from surface workings on New York claim of Copper Mountain group. Underneath the coating of malachite there is some azurite and cuprite, with limonite.



MINERALS AND ORE FROM COPPER MOUNTAIN AREA.

A. SMELTER AND SAWMILL AT HEAD OF COPPER HARBOR.
An aerial tramway leads from the mine workings to the smelter. Photograph by Winter & Pond.

B. HETTA MOUNTAIN FROM HEAD OF COPPER HARBOR.
Photograph by Winter & Pond.

Alaska Copper Co. also have been productive, and small shipments of copper ore have been made from the Corbin and Copper City mines. Most of the ore shipped from these mines contains over 100 pounds of copper and a few dollars' worth of gold and silver per ton. The quantity of ore mined, however, is relatively small, and the underground workings, except those of the Jumbo mine, are not extensive. Mining presents no serious difficulties, as most of the deposits

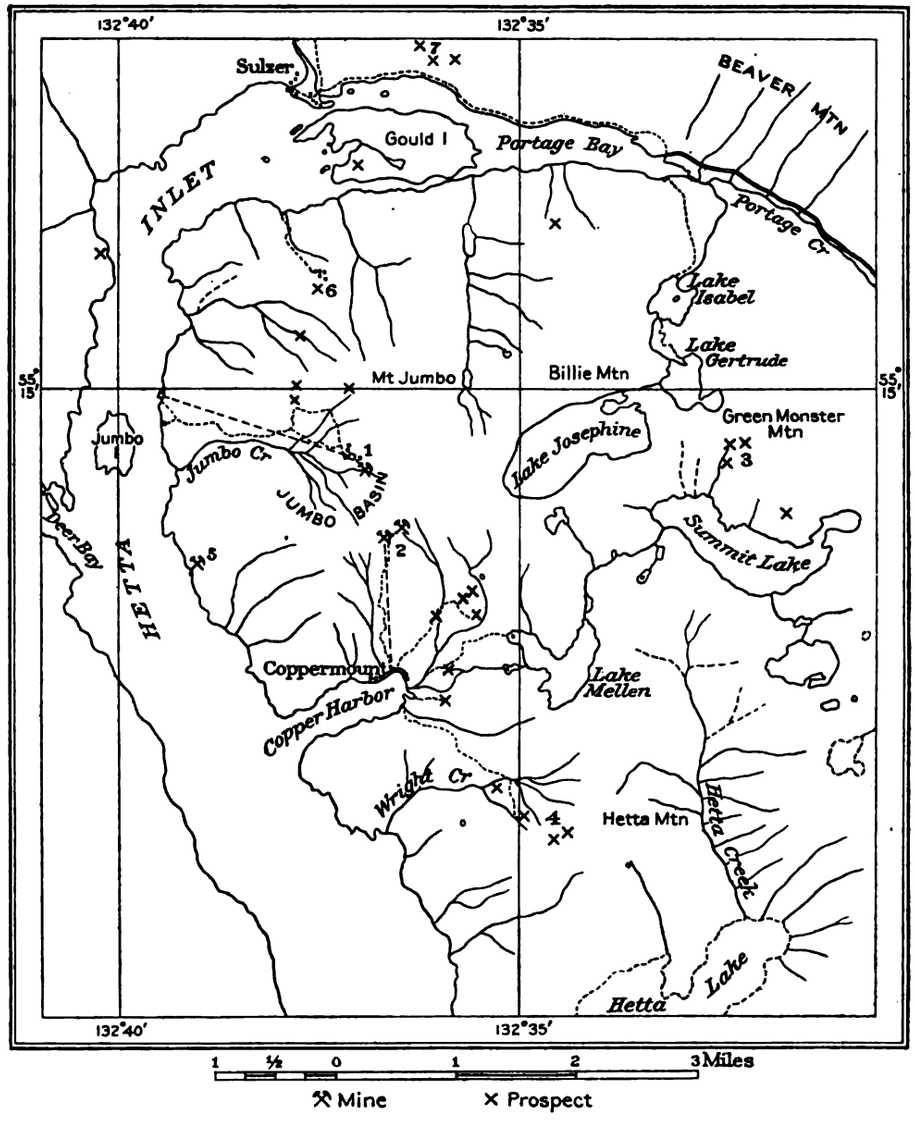


FIGURE 1.—Sketch map of the Copper Mountain area showing location of principal mines and prospects in 1908. 1, Jumbo mine, Alaska Industrial Co.; 2, Copper Mountain mines, Alaska Copper Co.; 3, Green Monster claims, Alaska Industrial Co.; 4, Hetta Mountain claims; 5, Corbin mine, Alaska Metals Mining Co.; 6, Houghton claims, Cuprite Copper Co.; 7, Sultana claims.

are located well up on the mountain sides, so that they can be developed by short tunnels, and the distance from the sea to most of the mines is only a few miles.

EARLY DISCOVERIES.

Mining development on Copper Mountain began in 1897, though the existence of copper ores in this region was known some years before by the natives who fished and hunted along the

coast. The first mining claims were located on the ridge just west of Copper Mountain peak, where copper carbonate and other oxidized ores outcrop. These claims were staked and recorded by Charles Reynolds and Thomas Wright in the autumn of 1897. In the same year the deposits in the Jumbo Basin were discovered by Aaron Shellhouse, but they were not recorded until the following spring. In 1898 many other claims were located on Copper Mountain, and also on Green Monster Mountain, to the east, and on Hetta Mountain, to the south. The first man to interest capital in developing the Copper Mountain properties was Henry W. Mellan, through whose efforts the Alaska Copper Co. was formed, and development work was started in 1899.

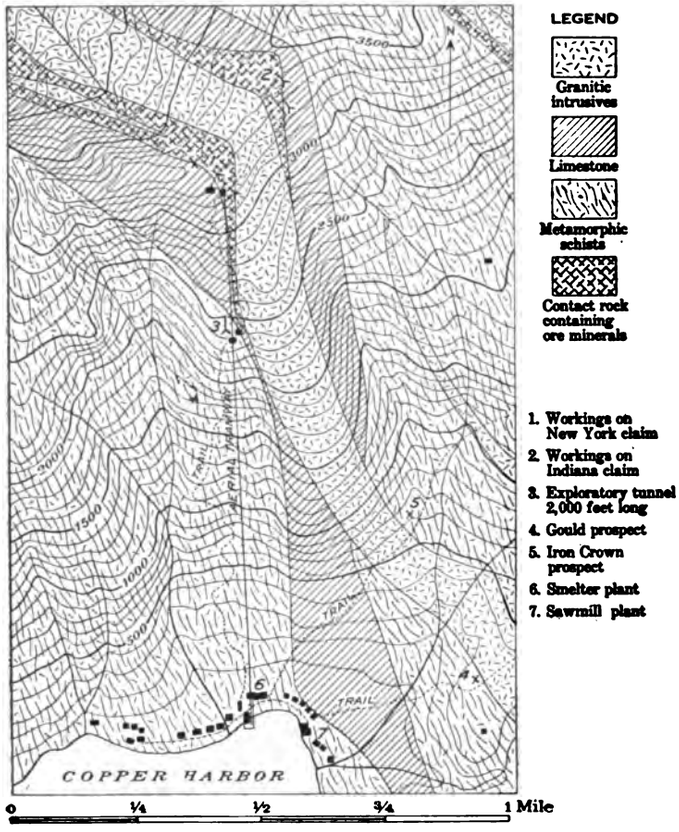


FIGURE 2.—Sketch map showing geology and mine workings on property of Alaska Copper Co. and adjacent mining claims in 1908.

The Jumbo Basin deposits, on the west slope of Copper Mountain, were visited in 1899 by William Sulzer, who recognized their value and formed the Alaska Industrial Co. to develop these deposits.

Many other claims were located in the vicinity of Copper Mountain between 1900 and 1903, including the Corbin, Houghton, Hetta Mountain, and the Sultana group.

THE MINES.

ALASKA COPPER CO.

Location of property.—The group of claims belonging to the Alaska Copper Co. occupies the south slope of Copper Mountain, extending from tidewater at Copper Harbor to the crest of the ridge at an elevation of 3,500 feet. (See fig. 2.) There are 18 claims in the original group, though developments have been advanced mainly on the New York and Indiana claims, which are on the top of the ridge.

Development.—The first developments were made by means of open pits on the outcrops of the ore deposits along the ridge, at altitudes of 3,300 and 3,400 feet. The lower of these outcrops is now (1908) on the New York claim, and tunnels 200 and 700 feet in length have been driven at levels 150 and 300 feet below the open pit to explore the deposit. These tunnels are connected by raises. Some stoping done in the tunnels showed that the ore was irregular in its occurrence and that it consisted of rich pockets of copper carbonate. In the low tunnel the carbonate ore is replaced by sulphides, which are more disseminated in the garnet gangue rock, though the rock contains also carbonate ores. This deposit has been explored at still greater depth by a tunnel 3,000 feet long, this measurement including crosscuts. This tunnel is run at an elevation of 2,350 feet and undercuts the surface outcrops of the ore deposit at a depth of nearly 1,000 feet. It follows the contact zone of the diorite, first with quartzite and next with limestone, and the tunnel itself zigzags from one contact to the other, usually keeping within the contact rock. Its general course is northeasterly to a point 1,400 feet from its mouth, where it branches, the left or northwestern branch continuing for several hundred feet along the contact to a

point almost directly under the surface outcrop on the New York claim and the northeastern branch penetrating the massive granite belt for 700 feet toward the Indiana lode. (See fig. 3.)

The principal developments on the Indiana claim are at a point 800 feet northeast of the open pit on the New York claim and at an elevation of 3,500 feet. Here a large open pit has been made and tunnels have been driven at different points, from 40 to 220 feet below the level of the pit, to investigate the deposit in depth. These openings are all in the contact rock and include about 600 feet of exploratory tunnels, crosscuts, and raises, but only small masses of minable ore have been found in them. An eastward extension of the tunnel at the 2,500-foot level would probably traverse the same contact rock at a depth of 1,150 feet below the surface. From the Indiana workings a surface tram, 1,400 feet long, extends around the mountain to the New York claim, from which an aerial tram extends to Copper Harbor. Pits, trenches, and short tunnels, most of them in the contact rock, have disclosed some ore on other claims belonging to this group, but no large masses have been found on these claims and the work done on them has been small. The total mine development up to the time the mine closed in 1907 consisted of about 4,200 feet of tunnels and 500 feet of shafts and raises, besides many open pits. The ore mined has been taken principally from the upper workings on the New York claim.

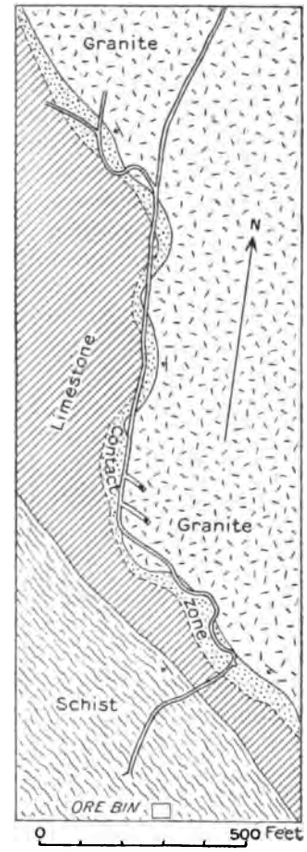


FIGURE 3.—Plan of long tunnel of Copper Mountain mine, showing rocks near contact zone.

Smelter.—The smelting plant stands close to tidewater at the head of Copper Harbor. It consists of a 250-ton Allis-Chalmers blast furnace, ore bins of 2,500 tons capacity, coke bins of 1,200 tons capacity, and a sampling mill, besides the usual appliances for granulating and removing slag. (See Pl. XI, *A*.) The ore from the mine workings is delivered to the sampling mill bin by an aerial tramway 6,000 feet long, and the ore shipped to the smelter is unloaded on the wharf into receiving bunkers of 1,000 tons capacity, from which it is drawn off into cars and hoisted on an inclined tramway to the sampling mill.

In addition to the smelting plant there is a sawmill, machine shop, store and warehouse, assay office, and compressor plant. The power required for the smelter and compressor plant was derived from Reynolds Creek, the water being transmitted 1,000 feet by a 22-inch pipe line to two 300-horsepower Pelton wheels.

The smelter was first blown in for a run in June, 1905, and was operated for short periods during 1906 and 1907. The mines above the smelter did not furnish enough ore for the furnace and for fluxing and it became necessary to go to other mines for ore. The Rush & Brown mine, on the east coast of the island, was therefore leased by the Alaska Copper Co., and small lots of ore were purchased from other mines on Prince of Wales Island. The smelter was run at intervals on these ores until early in 1907, when it was shut down, and no attempt has yet been made (1912) to operate it again.

Ore deposits.—The two principal ore deposits that have been developed on the New York and Indiana claims are contact deposits separated from one another by a belt of diorite 800 feet wide. Along both sides of this belt of intrusive rock lie zones of contact rock, composed essentially of garnet-diopside and epidote, and in these zones the ore is found either scattered or in concentrated masses. At the surface workings on the New York claim a mass of rich ore occurs in the contact rock between the diorite and limestone, the limestone forming the hanging wall. (See Pl. VI, *B*, p. 32.) Most of the copper ore, which was originally chalcopyrite, has been altered to copper carbonates and limonite, and these secondary ores have spread out into the somewhat fractured limestone hanging wall. This spreading, which is attributed to the action

of meteoric waters, in few places extends more than 50 feet into the hanging wall. On the surface this ore mass appeared to be extensive, but in the tunnels below the surface pit it was rather small, and in the long tunnel that follows the contact for 2,000 feet only scattered chalcopyrite was found and no minable ore. (See fig. 3.) In the upper tunnels the secondary ores were less prominent than in the surface pit and in the long tunnel they were entirely absent. The contact rock exposed along the surface and in the long tunnel ranged in width from a few feet to 50 feet. In two places veins of this contact rock that occupied fissures in the diorite had been followed for short distances by crosscuts from the main tunnels. The contact rock contained inclusions of both the limestone and the quartzite. Faulting and slipping planes were observed within the contact rock, but the displacements along these were slight.

The contact deposit on the Indiana claim is on the eastern contact of the diorite belt. Quartzite and amphibolite cut by numerous quartz stringers form the hanging wall, though the contact rock includes masses of limestone. The garnet and epidote minerals of the contact rock have penetrated and altered these quartzites for a few hundred feet away from the contact. The ore exposed in the open pit and tunnels is similar to that on the New York claim, though it is less concentrated, and the valuable metals it contains are more scattered. The ore mined from this deposit contained only a little copper and from $1 to $2 in gold and silver. At both the New York and Indiana contact deposits there is a gradual change or blending of the contact rock and ore into the diorite, due to replacement of the minerals composing the diorite by those composing the contact rock. This zone of partial replacement is generally from 2 to 5 feet wide. The contact action is fully discussed under a separate heading (p. 102).

ALASKA INDUSTRIAL CO.

Location of properties.—The present (1908) holdings of the Alaska Industrial Co. in the Copper Mountain area include the Jumbo group (29 claims) and the Green Monster group (14 claims) located on Green Monster Mountain. (See Pl. IV, *A*, p. 29.) The mining developments here described include only those made up to 1908. Since then some other notable advances have been made.

JUMBO GROUP.

The claims of the Jumbo Group occupy the slopes of Jumbo basin, on the northwest side of Copper Mountain. These claims extend from a point 500 feet in elevation and a mile from tidewater nearly to the mountain summit, which stands at an elevation of 3,946 feet. The main deposits being explored lie at elevations between 1,500 and 1,900 feet, on the east slope of Jumbo Basin, on Jumbo claims Nos. 1, 1A, and 2, and between elevations of 1,500 and 2,000 feet on Jumbo claims Nos. 4 and 14. Practically all the ore mined and shipped has been taken from the deposits on Jumbo claim No. 4.

Development.—The deposits included in the Jumbo group were first exploited in 1902, and during succeeding years numerous prospect tunnels were driven and test pits sunk on the different claims. After a promising ore body had been opened on claims Nos. 4 and 14, located at elevations of 1,700 and 2,050 feet above sea level, it was necessary to devise a means of transporting the ore to tidewater. For this purpose a Riblett aerial tram 8,250 feet long and an additional tram 600 feet long were erected in 1905–6, thus connecting the beach with the lower tunnel of the mine workings, 1,700 feet above sea level. At the beach a wharf with a frontage of 150 feet was built and ore bins of 4,000 tons capacity were erected. While this work was in progress the development of the ore deposits was advanced, and early in 1907 shipments of the ore to the Tyee smelter, in British Columbia, were begun. In 1908 the mine workings on Jumbo claim No. 4 consisted of four tunnels at elevations between 1,570 and 1,950 feet, and an open cut at an elevation of 2,050 feet. (See fig. 4.) The main working tunnel, or tunnel No. 3, is at an elevation of 1,700 feet. At a point 180 feet from its mouth a 130-foot vertical raise connects this tunnel with the stopes in the ore body and with tunnel No. 2. At a point 40 feet above tunnel No. 3 a stope has been extended to the west and 30 feet above this an exploratory drift has been run eastward into the ore. The floor of the main

stope is 100 feet above the level of tunnel No. 3. This stope is 240 feet long, 10 to 40 feet wide, and extends for 30 feet above the level of tunnel No. 2. A second sulphide body, separated

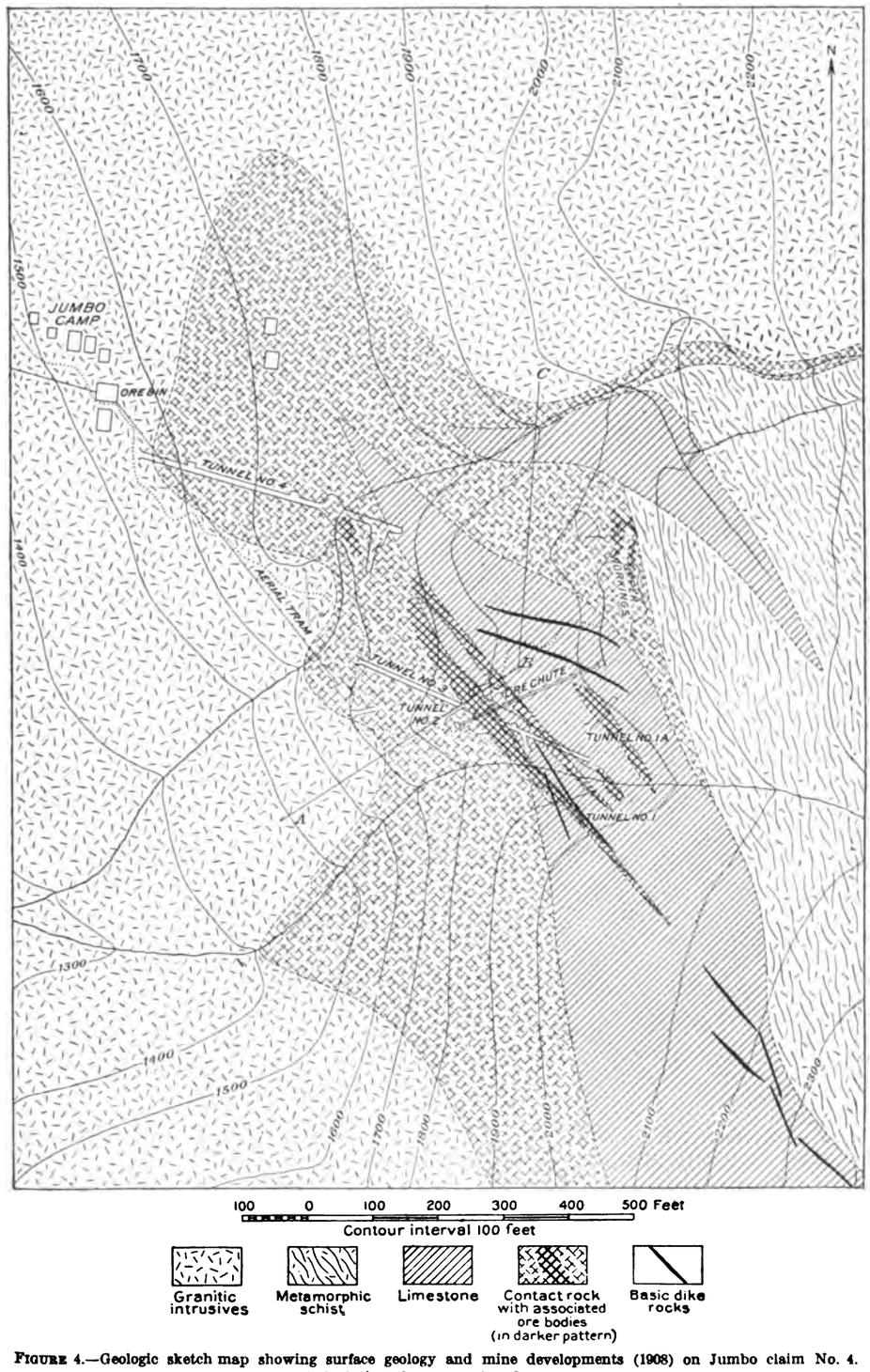


FIGURE 4.—Geologic sketch map showing surface geology and mine developments (1908) on Jumbo claim No. 4. *A B C*, line of cross section, figure 5.

from the main deposit by 40 feet of contact rock, has been opened on level No. 2, northeast of the main deposit, and has yielded a large quantity of ore. The ore from these two ore bodies

goes through the raise to tunnel No. 3, where it is trammed to the upper terminal of the aerial tramway, from which it is carried to the ore bunkers at the shore.

The southeastern extension of these deposits is being explored by tunnels in Canyon Creek. In tunnel No. 4, which is at an elevation of 1,570 feet, just above the upper terminal of the tramway, two small ore bodies were crosscut and yielded a small quantity of ore. These bodies may represent the northwestern extension of the two ore deposits opened in tunnel No. 2. This level is being advanced to undercut the raise in tunnel No. 3 and will eventually serve as a passageway for all the ore mined from the workings above, thus eliminating the necessity of the auxiliary tramway from tunnel No. 3.

The uppermost workings consist of an open cut across a width of 200 feet at an elevation of 2,050 feet, on Jumbo claim No. 14. In this cut the irregularity and sporadic occurrence of the ore is well shown. At one point a face of massive sulphide ore 6 feet across is surrounded by barren gangue rock; at other points sulphides were finely disseminated in the rock in sufficient amounts to make a minable ore.

The developments on Jumbo claim No. 1 have been extensive and have exposed a large body of low-grade ore. The uppermost workings are at an elevation of 1,890 feet and consist of an open cut exposing considerable copper carbonate and limonite ore in the contact rock. This carbonate, however, does not extend to a great depth. Just below this cut the deposit is exposed in a steep bluff 100 feet high and 100 feet wide, along the foot of which the ore consists of masses of sulphides accompanied by magnetite. Below and west of this point, at an elevation of 1,660 feet, a tunnel crosscuts the limestone hanging wall and enters the contact rock, which at that point was barren. Another larger bluff of ore is exposed east of this tunnel, at an elevation of 1,580 feet, on Jumbo No. 2 claim. This deposit, known as the magnetite body, has been undercut by two tunnels, one at 1,540 and the other at 1,480 feet. The upper tunnel starts in the magnetite deposit, penetrates it for 50 feet, and enters the diorite footwall for 6 feet. The contact between the ore body and the footwall showed a gradation from the contact rock and the intrusive rock, though the gradation was rather abrupt. Near the contact the ore is of fine texture, is rich in diopside and magnetite, and contains disseminated sulphides, whereas at the entrance to the tunnel the gangue is essentially garnet and calcite, with small masses of chalcopyrite. The lower tunnel crosscuts the limestone hanging wall for 55 feet and penetrates the ore body for 10 feet. The contact between the ore body and limestone is sharply defined. The downward extension of this ore body is exposed on Jumbo claim No. 1A by two tunnels, one above the other, at elevations of 750 and 840 feet. The upper tunnel crosscuts a hanging wall of schist that is largely replaced by the contact rock and enters the sulphide ore 25 feet from its mouth. In the lower tunnel, which is 240 feet long, the hanging wall consists of a banded quartzite or silicified schist, which grades into banded contact rock containing disseminated sulphides and magnetite. The inner end of the tunnel extends into the diorite footwall. The contact deposit exposed in this tunnel is 100 feet wide, but the ore in it is scattered and is of lower grade than the ore exposed in the upper tunnels. Explorations on Jumbo claim No. 3, which lies between the workings on Jumbo claims Nos. 2 and 4, have exposed other deposits of chalcopyrite and magnetite, on which developments are being advanced. Disseminated deposits of sulphides in the schists have been explored by tunnels and open cuts on Jumbo claims, but the metallic content of the ore exposed was low.

Ore deposits.—The general relations of the rocks of this area, which are similar to those in the Copper Mountain group, already described, are presented on the geologic map (Pl. I, p. 16) and in the sketches of the mine workings (figs. 4 and 5). The main diorite mass forms the footwall of the deposits, the hanging wall being in some places a crystalline limestone and in others a silicified schist or banded quartzite much metamorphosed and varying in color from gray to greenish and reddish.

The copper deposits being mined on Jumbo claim No. 4 consist of irregular bodies of chalcopyrite-pyrrhotite ore, 10 to 40 feet wide and 100 to 200 feet long, One mass has been opened for a depth of 150 feet, but the extent of the others is not known. The contact zone

A. MASS OF LIMESTONE INCLOSED IN CONTACT ROCK.

Point of hammer rests on reaction rim composed essentially of amphibole. (See Pl. VIII, *C*.) View taken just below tunnel No. 1, Jumbo claim No. 4.

B. MASS OF CHALCOPYRITE ORE INCLOSED IN CONTACT ROCK.

Dark patch on right is massive chalcopyrite. View taken just above mouth of tunnel No. 2, Jumbo claim No. 4.

within which these masses occur (see figs. 4 and 5) lies between the granitic intrusive and a belt of limestone, above which metamorphic schists appear. This mineralized zone is nearly surrounded by the granitic contact and in this respect differs from the other contact deposits.

No definite line of separation between the contact rock and the granitic intrusive can be drawn, as the mineral solutions appear to have replaced the mineral components of the rock adjacent to the contact. The beds of limestone on the hanging-wall side of the contact zone are fractured and faulted and masses of limestone are completely inclosed in the contact rock. (See Pl. XII, *A*.) On the other hand, masses of the contact rock are surrounded by the limestone, suggesting the replacement of the limestone by ore-bearing minerals. The contact rock is composed mainly of garnet, diopside, epidote, and some calcite, and these minerals are in places so closely associated as to resemble a compact felsitic rock, so that the rock might be mistaken for felsite. Near the ore masses the contact rock is generally coarsely crystallized, the garnet, epidote, and diopside forming aggregates of well-developed crystals and the calcite filling the interstices between the crystals. In the ore bodies the chalcopyrite occurs in small masses or is scattered through the inclosing contact rock and is associated with pyrrhotite and pyrite. Except the local change in the character of the crystallization of the contact rock there are no indications within the contact zone that may be used as a guide in the search for these ore masses.

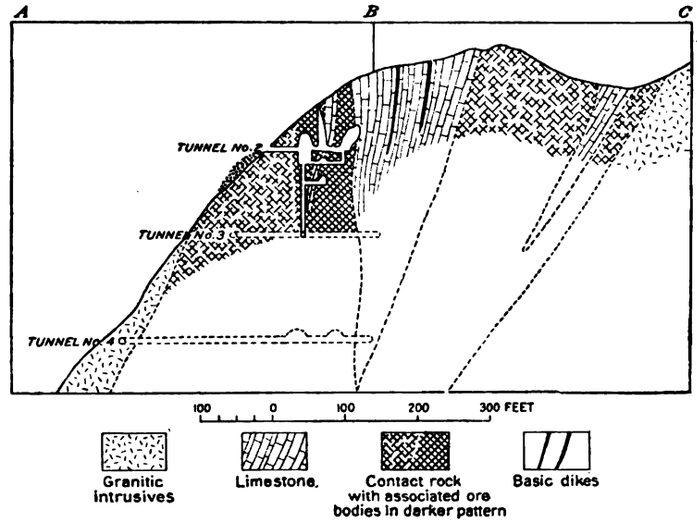


FIGURE 5.—Cross section along line *ABC* on figure 4, showing geology and mine developments (1908) on Jumbo claim No. 4.

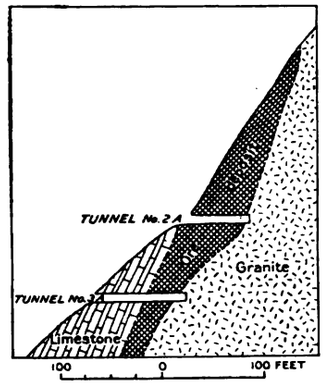


FIGURE 6.—Cross section of magnetite deposits on Jumbo claim No. 2 (1908).

The ore bodies on Jumbo claims Nos. 1 and 2, though similar in most respects to those on Jumbo claim No. 4, contain less copper and more magnetite, a mineral that was notably absent from the deposit on the Jumbo No. 4. The ore bodies have been well exposed by erosion over broad areas and in places are in the form of a sheet a few feet wide overlying the diorite footwalls. (See fig. 6.) These outcrops occur between the 1,500 and 2,000 foot contours, above which the diorite alone was observed. The width of the contact rock between the hanging wall and footwall varies from 10 to 100 feet, though in places the diorite and limestone lie in direct contact. The ore bodies within this contact zone are from 5 to 50 feet in width and a few hundred feet in length. They have not been developed to any considerable depth. The ore masses are confined to the diorite footwall and are sporadic in their occurrence, though they are connected with one another by more or less barren gangue or contact rock. The average ore from this deposit contains a high percentage of iron and nearly sufficient silica for smelting. (See fig. 6.) The ore carries not only copper but gold and silver.

GREEN MONSTER GROUP.

Situation.—The Green Monster group of claims occupies the northern and western slopes of Green Monster Mountain, 2½ miles east of Copper Mountain and 3 miles from the tide flats at the head of Portage Bay, from which a route, partly by trail and partly by boat, crossing

two lakes each half a mile wide, at altitudes of 600 and 1,680 feet, respectively, leads to the principal mine workings, at an elevation of 2,800 feet. Another approach to these claims, also partly by trail and partly by boat, is from Copper Harbor, as indicated on the map (Pl. II, p. 28) and on figure 1.

Development.—Although these claims were located in 1900, developments up to 1908 have been meager, and no attempt has been made to advance the exploration beyond the required assessment work. Two tunnels have been driven, each 65 feet long, one on Green Monster claim No. 1 and the other on Diamond B. claim. On the Iola claim a pit 8 feet deep has been sunk and trenches have been dug along the ore body.

Ore bodies.—Ore bodies at the contact of the limestone and diorite are found on the Iola, Black Warrior, and Diamond B. claims. The deposit on the Iola claim has been opened by a small pit and by surface stripping and consists of a mass of magnetite-chalcopyrite ore, 10 feet wide, inclosed in the garnet-epidote gangue, which at this point occupies a width of about 25 feet between the limestone hanging wall and the diorite footwall. Along this contact other smaller ore masses were observed on the Iola and Black Warrior No. 2 claims, but they were apparently of little consequence. On the Black Warrior claims Nos. 1 and 5 similar ore deposits lie adjacent to the contact of the diorite and limestone and in a black slate band that extends along the mountain crest, striking N. 30° W., but these deposits have not been prospected. On the Diamond B. claim a tunnel 65 feet long has been driven along the contact of the limestone with a porphyritic dike 50 feet or more in width, striking N. 30° E. The main contact of the diorite lies about 150 feet to the west. The face of the tunnel is in limestone and in the tunnel the garnet-epidote vein rock is exposed across a width of about 10 feet and for a length of 50 feet. Small masses of copper sulphide occur in this contact rock, but the metal content of the vein as a whole is low.

A vein deposit filling an irregular fissure in the limestone occurs on Green Monster claim No. 1. This vein appears to be an offshoot from the main contact zone just west of it. The vein is undercut by a tunnel 65 feet long and is exposed by trenches for 250 feet along the surface. The vein strikes S. 20° E., dips vertical, and averages 6 feet in width. The copper occurs in small masses and disseminated particles throughout the garnet-epidote-calcite gangue. Associated with the chalcopyrite ore is pyrite, and in places along the surface limonite, malachite, and azurite occur.

A third type of mineralization is exposed on Black Warrior claim No. 2, where a narrow vein containing galena, pyrite, and chalcopyrite has been deposited along the contact of a porphyry dike and the limestone country rock at a point about 1,000 feet from the granite contact. This ore, though of good quality, has not been found in large quantity.

In general the ore bodies on the Green Monster group are similar to those on the Jumbo group, but do not appear to be as great in size and extent. The position of the property necessitates the building of a tramway for 3 miles in order to ship the ore, and conditions of mining are less favorable here than at many other points along the coast.

CUPRITE COPPER CO.

Situation and development.—The property of the Cuprite Copper Co., known as the Houghton group of claims, is on the northwest slope of Mount Jumbo, between elevations 1,000 and 2,000 feet, and is 1 mile from Hetta Inlet. (See fig. 1.) They include the diorite contact zone exposed on the Jumbo group to the south, and the ore bodies under exploration are of the same general type. The claims, including a mill site at tidewater, were located in 1901, and from that time to the end of 1905 the developments were meager, assessment work alone being done. Early in 1906 the properties were acquired by the Cuprite Copper Co., two more claims were located, and active development was begun and was continued during 1907 and 1908. The present mining camp is at an elevation of 1,500 feet and the mine workings between 1,600 and 1,700 feet. A tunnel at an elevation of 1,600 feet, 100 feet long, and another at 1,700 feet, 80 feet long, had been driven in 1908 to explore the ore body along the contact, its surface

exposure being 100 feet above. At other points on these claims short exploratory tunnels and cuts have been made.

Ore body.—The copper deposits on which explorations are being made is included in the garnet-epidote contact rock, which occupies a zone 25 to 75 feet wide between the diorite and limestone. This zone strikes N. 45° E. and dips steeply to the northwest. The ore body is developed on the surface by a 30-foot cut and a 15-foot pit, in which a body of massive chalcopyrite ore 5 feet wide is exposed. In the tunnels that enter the contact zone small amounts of copper ore have been found but no large ore body. The chalcopyrite is associated with magnetite, pyrite, and some pyrrhotite. These claims showed less general contact metamorphism and less ore than the Jumbo group.

SULTANA GROUP.

Situation and development.—The Sultana group, consisting of six claims, is on the north side of Hetta Inlet, about a mile east of Sultana, and extends from tidewater to an elevation of 1,000 feet on the south slope of Beaver Mountain. The principal developments have been made on the Sultana claim, though prospecting has been advanced on the adjoining claims, the Index and Vulcan. The total work done each year up to 1908, however, amounts to little more than the assessment work.

Ore bodies.—The ore bodies exposed are contact-metamorphic deposits underlain by a granitic intrusive, banded siliceous limestone forming the hanging wall. A gangue of garnet and epidote, with considerable calcite, has been deposited along the contact, in which sulphides of copper and iron are sparingly distributed in small masses and disseminated particles.

At a point on the Sultana claim at an elevation of about one-third of a mile from the shore a tunnel 130 feet long was driven in the granodiorite footwall without discovering ore. Another tunnel 430 feet in elevation exposes at its entrance a mass of chalcopyrite ore 3 feet wide and then crosscuts the garnet-epidote gangue rock for 25 feet, showing practically no ore. On the Index claim, which is east of the Sultana claim, at an elevation of 600 feet, an open cut 60 feet long exposes small amounts of chalcopyrite, not sufficient to make a profitable ore, associated with magnetite and pyrrhotite in banded garnet-epidote rock. On the Vulcan claim, north of the Sultana claim, at an altitude of 520 feet, is an open cut 60 feet wide. Here garnet-epidote rock occurs with large included fragments of banded limestone containing pyrrhotite and chalcopyrite in masses a few feet wide. A relatively small amount of ore is developed on these properties. The ore at this prospect was reported to carry cobalt in considerable amount, but a sample taken by the writer and submitted for analysis gave only a trace of cobalt and less than 0.2 per cent of nickel.

ALASKA METALS MINING CO.

Situation and development.—The property of the Alaska Metals Mining Co., formerly the Corbin mine, is close to tidewater on the east side of Hetta Inlet, 1½ miles north of the entrance to Copper Harbor. This property, which includes four claims, was located in February, 1905, and the following summer ore was shipped to the smelter at Coppermount. Early in 1906 the mine was sold to the Alaska Metals Mining Co., which began active development and equipped the property with an air compressor, a hoist, and a steam-power plant and erected a small wharf and several buildings. The position of the ore body necessitated the sinking of a shaft 100 feet, and at this depth considerable crosscutting and drifting were extended to explore the ore body at this level. A tunnel, started near the shaft, has been driven along the vein for 210 feet, but the results were not encouraging. Operations on this property were suspended during the winter of 1907 and were not renewed in 1908.

Ore bodies.—The ore body is a vein deposit of nearly massive sulphide ore inclosed in a narrow fissure parallel to the stratification of the greenstone schist country rock. The vein is from 1 foot to 3 feet wide and has been exposed for about 250 feet, for which distance it strikes N. 70° W. and dips 70° SW. A tunnel 210 feet long was driven southeastward along the vein and in this tunnel the vein narrows to a thin gouge seam and widens again at several points, its continuation being indicated by the bleached appearance of the country rock. The footwall of the

vein is a dark-green schist and appears less altered than the hanging wall, which is a pale-green talcose schist. Grooves caused by slipping were observed on both the footwall and the hanging wall. These grooves pitch 50° NW., and the ore shoots most likely follow this direction. In the vein itself occasional slickensides were observed, indicating movement since the deposition of the ore. The vein is cut by dikes of diabase, 2 to 4 feet wide, striking N. 10° E. and dipping 70° NW., nearly at right angles to the prevailing rock structure. The ore is principally pyrite, containing chalcopyrite associated with some quartz and calcite as gangue minerals. Besides the small quantity of copper, the ore carries, as reported, gold and silver amounting to about $3 per ton. Explorations at other points on these claims may reveal similar vein deposits.

COPPER CITY MINE.

Situation and development.—The Copper City mine, also known as the Red Wing group, consisting of four claims, is near tidewater on the east side of Hetta Inlet, 7 miles south of Copper Harbor. This property has been a copper producer in a small way ever since operations first began, in 1903, the ore being sacked and shipped to the Tacoma smelter. The developments up to 1908 have been confined to the Red Wing claim, where the vein deposit has been opened by an inclined shaft 120 feet in depth. From this shaft two levels, 50 and 100 feet, respectively, below the surface have been driven. The 100-foot drift is the working level and this has been carried along the vein for 200 feet north and 50 feet south of the shaft. At a point on the level 75 feet north of the shaft a 60-foot winze has been sunk and from this a drift 50 feet long has been run. Most of the ore above the 100-foot level has been mined, and it is proposed to sink the shaft an additional 100 feet and open up a 200-foot level.

Ore body.—The ore body, a vein deposit of nearly massive sulphide ore, is inclosed in a slate-greenstone country rock parallel to the bedding and corresponds in general character to the ore body at the Corbin mine already described. The country rock grades from a black slate or siliceous schist to an amphibole schist or altered greenstone, the general strike being N. 20° E. and the dip 60° NW. These schists and also the vein deposits are crosscut by several diabase dikes, 1 foot to 5 feet wide, which strike about N. 30° W. These dikes were intruded after the main ore deposition, but subsequent mineralization has deposited small amounts of mineral in veinlets in them, and the ore bodies, where crosscut, usually continue along the same line of strike on opposite sides of these intrusives. The vein as exposed in the shaft varies from 6 inches to 4 feet in width, narrowing to a gouge seam at a depth of 100 feet. At this level the vein appeared to be displaced for a short distance toward the footwall side, where it was again found, and on it a 60-foot winze was sunk, in which the vein was reported to be wider. Similar but smaller veins, trending parallel to the main vein, have been exposed by surface cuts and trenches at other points on the property, but none of these have been developed.

The ore is composed essentially of chalcopyrite, pyrite, sphalerite, and rarely hematite (specularite), associated with quartz, calcite, and epidote as gangue minerals. Surface oxidation has altered the chalcopyrite in places to limonite and cuprite, and along joint cracks in the country rock malachite and small films of native copper were observed. In addition to copper each ton of the ore contains gold amounting to $3 to $6 and silver amounting to $1 to $3, as well as 6 to 9 per cent of zinc.

PROSPECTS ON GOULD ISLAND.

Gould Island, which lies south and east of Sulzer, is about 2 miles long and less than 1 mile wide. It is composed essentially of limestone, siliceous schists, and slate intruded by a diorite mass which occupies the eastern portion of the island. The prospects are at the southwest end of the island. The ore, which consists of galena, sphalerite, and chalcopyrite, occupies small veinlets, and is finely disseminated in a belt of siliceous limestone 30 feet wide, striking east and west, and dipping steeply north. Associated with the ore are calcite, quartz, garnet, epidote, and large amounts of wollastonite, which occurs in the adjacent limestone in radiating masses. A tunnel 70 feet long, driven along the footwall of this mineralized belt, where it is in contact with slate, disclosed scattered occurrences of ore. Just north of the tunnel is an open cut

and a shaft, 10 feet deep, exposing mineralized rock of the same character. About 300 feet east of these workings is another open cut and a pit, 10 feet deep, on the same belt. The ore exposed on these claims at the time of the writer's examination, in 1908, was small in amount and of low grade.

PROSPECTS AT HEAD OF COPPER HARBOR.

The prospects at the head of Copper Harbor, indicated on Plate II (p. 28), except the Paris vein, are all contact-metamorphic deposits and lie adjacent to the same granodiorite batholith that is exposed on the Copper Mountain and Jumbo groups. On none of these claims did the developments up to 1908 exceed the assessment work required. On the Paris group of claims, at an elevation of 300 feet, about half a mile from the beach, a tunnel 115 feet long has been driven along a small quartz vein, striking northeastward and carrying a low content of copper and gold. The country rock is a banded quartzite striking N. 40° W. and dipping 40°–60° SW. The Gould group, which lies north of Reynolds Creek, half a mile from Copper Harbor, at an elevation of 300 feet, is located along the contact of the diorite with quartzite, which at this point strikes S. 20° E. A 50-foot tunnel crosses the contact rock and enters the granite, in which also small amounts of chalcopyrite and pyrrhotite are scattered near the contact in fine particles. A 40-foot shaft at the mouth of the tunnel exposes the mineralized garnet-epidote rock, showing a banded structure striking parallel with the contact and dipping 60° SW. About a mile northeast of the Gould group and at an elevation of 100 feet is the Russian Bear claim, and adjoining this on the north is the Texas claim, at an elevation of 1,450 feet. The contact-metamorphic deposits on both these claims flank the western slope of the granodiorite batholith, and the developments consist mainly of open cuts and trenches, in which only small masses of ore have been exposed.

PROSPECTS ON HETTA MOUNTAIN.

Hetta Mountain, which lies southeast of Copper Harbor, is made up essentially of limestone and quartzite, its northern slope, as indicated on Plate V, being bordered by the granodiorite intrusive. Two claims have been located on contact deposits along the intrusive contact about a mile from Copper Harbor, at an elevation of 900 feet. In 1908 the ore bodies had been prospected by three tunnels, one 20 feet, one 25 feet, and one 30 feet in length, and several open cuts in which small masses of chalcopyrite and pyrrhotite are exposed in the garnet-epidote contact rock. The quartz schist country rock on the south, which forms the hanging wall of the deposits, strikes east and west, has a nearly vertical dip, and is intersected by granitic and pegmatitic dikes.

In a gulch at an elevation of 1,380 feet another prospect is located on a vein deposit consisting of garnet with some epidote and sulphide ores in the siliceous schists. Here, at a point where a small mass of chalcopyrite ore is exposed, a tunnel 30 feet long has been driven on the vein. On the ridge of Hetta Mountain the quartzites alternate with beds of limestone which strike N. 80° E., and which are intruded here and there by masses of granodiorite. Along the contact of one of these dikes on the north slope of the ridge, at an elevation of 2,480 feet, there is a contact-metamorphic deposit which contains both the sulphide and the carbonate of copper. A tunnel 15 feet long and considerable stripping constitute the developments and expose small masses of the copper ore in a garnet gangue. Southeast of this prospect, on the opposite side of the ridge, at an elevation of 2,500 feet, an iron capping has been explored by trenches in which also small amounts of copper ore are exposed.

KASAAN PENINSULA.

TOPOGRAPHY.

MAIN FEATURES.

Kasaan Peninsula is a promontory on the east side of Prince of Wales Island that includes about 60 square miles and lies between 132° 5′ and 132° 35′ W. longitude and 55° 25′ and 55° 40′ N. latitude. (See Pl. XIII, in pocket.) Seen from a steamer on Clarence Strait the

peninsula appears to be an island, whose summits are highest near its central part and diminish in height toward the north and south. A neck of low land between the head of Kasaan Bay and the south end of Thorne Bay connects the peninsula with Prince of Wales Island. This low pass appears to represent the continuation of a valley, from 8 to 10 miles wide, which is tributary to the north branch of Thorne Bay and extends northwestward through the center of Prince of Wales Island. Kasaan Bay, which is 18 miles long and 1½ to 4 miles wide, occupies the south end of this valley. In the northward extension of this valley and on the low pass south of Thorne Bay there are many small lakes and morainal deposits, which will be mentioned later.

The highest point on the peninsula is the top of Kasaan Mountain (Pl. XIV, *A*), which has an altitude of 2,840 feet. The other mountains average about 2,000 feet in height and their slopes are deeply dissected by small valleys and by narrow steep-sided gulches.

LEVELS OF EROSION.

On Kasaan Peninsula there are many flat areas, some of them containing small lakes, and the mountain slopes themselves are interrupted by benches or terraces (Pl. XIV, *C* and *D*), which occur at different elevations and apparently at rather regular intervals above sea level. These benches represent levels of erosion.

The lowest bench level is indicated by a series of flats or forelands at a height of about 50 feet above sea level. (See Pl. XIV, *D*). Forelands at this height are especially prominent at the head of Kasaan Bay and on the adjacent islands. Along the northern shore of the peninsula and in Tolstoi Bay a higher level of erosion, which seems persistent at 100 to 150 feet on many parts of the peninsula, is marked by wide flats in the valleys, some of which are occupied by small lakes. Such flats occur just north of Grindall Point; on the hills just north of Kasaan; northeast of the Haida mine, where the flat is covered by a lake; on both the east and west slopes of Tolstoi Bay; and southwest of Thorne Bay, where there are two large lakes.

Still higher, at an elevation of 250 to 300 feet, a level of erosion is represented by a flat, occupied by a lake, at the head of Poor Mans Creek, on the divide toward Tolstoi Bay; by flats north of the Alarm claim, on which there are several lakes; and by several areas occupied by lakes northeast of the Haida mine. The surface of the lake just east of Lake Three, at the head of Kasaan Bay, and that of the lake below the Goodro mine are also at this elevation.

The next or fourth series of benches and flats are prominent at an elevation of about 500 feet above sea level. At this level also there are lakes, from which small streams flow down through gulchlike valleys to lower levels. At this altitude there are terraces along the north slope of the southwest half of the peninsula, flats south of Hadley, a low pass across the peninsula southwest of Lyman Anchorage, and the lakes and flats on the divide from Windfall Harbor to Tolstoi Bay and east of the It mine. Most of the summits of the hills north of the It mine and adjacent to the Salt chucks at the head of Kasaan Bay are at an elevation of about 500 feet.

Higher levels of erosion are indicated at elevations of 1,100 and 1,300 feet by lakes and flats in the central portion of the southeast half of the peninsula, by flats that are in part occupied by lakes on Mount Andrew and on the mountain just west of Lyman Anchorage, and at the head of a branch of Tolstoi River. Other lakes at an altitude of about 1,500 feet north of Grindall Point Mountains and north of Kasaan Mountain may mark a higher erosion level.

The highest relatively level areas stand at an altitude of about 1,850 feet, on the Grindall Point Mountains, where there are also small lakes, though they are not shown on the map; also on the ridge southeast of Kasaan Mountain and on Tolstoi Mountain.

GLACIATION.

The mountain mass of Kasaan Peninsula exhibits characteristic glaciated topography. That the entire peninsula was at one time overridden by ice streams is evident from the glacial erratics which lie on the highest summits, the moraine deposits which occur on the lower levels, and the many basins which stand at various elevations on the mountain slopes and are now occupied by lakes. (See Pl. XIV, *C*.) During the period in which this area lay beneath the

A. VIEW SOUTHEASTWARD FROM KASAAN MOUNTAIN.

B. NORTH SIDE OF KASAAN MOUNTAIN.

C. TOPOGRAPHY ON SUMMIT OF GRINDALL MOUNTAIN.

Showing small lake basins and scrub pine above timber line.

D. FORELANDS ALONG NORTHEAST SIDE OF KASAAN BAY.

Mountains on Kasaan Peninsula in background. View taken from point at entrance to Salt Chuck at head of Kasaan Bay

ice many of the minor topographic features, such as the earlier erosion level, were partly destroyed. Some of the valleys were more deeply eroded, lake basins were formed, and wide areas of glacial silt and débris were laid down. This section of the ice stream is well represented in the northern extension of the valley of Kasaan Bay, which is occupied by a chain of connecting lakes, on the sides of which thick beds of glacial clay and débris have been exposed by subsequent stream erosion. This valley probably represents a preglacial river floor, and only the lake basins and minor physiographic features can be attributed to ice erosion.

Erosive action subsequent to the ice period has formed the gulches and ravines which are everywhere prominent on the mountain slopes.

Another noteworthy feature of Kasaan Peninsula is its precipitous southwest slope, which is much steeper than that on the northeast. This difference may be due to the fact that the ice stream remained longer in the valley of Kasaan Bay than in that of Clarence Strait, the action of the ice tending to deepen the valley and at the same time to protect the mountain slopes from surface erosion.

FORESTS.

Kasaan Peninsula is densely forested with spruce and hemlock, principally hemlock, which extends to elevations of 1,500 to 1,800 feet. (See Pl. XIV, *C*.) The timber, especially that on the southwest side, toward Grindall Point, is large and straight. The mountain side is steep down to salt water, so that the timber is easily accessible. The mountain summits and ridges above timber line are fairly open and bear relatively little vegetation as compared with that of the densely forested lower levels (Pl. XIV, *D*), groups of scrubby pine and juniper and a low berry bush being the principal plants found.

Prince of Wales Island was included in the Tongass National Forest, but in 1908 that portion of Kasaan Peninsula which lies south of the Hole in the Wall (the boundary line is indicated on Pl. XIII) was taken out of the national forest.

GEOLOGY.

GENERAL FEATURES.

The geology of Kasaan Peninsula displays strikingly the phenomena of igneous intrusion and contact metamorphism. The geologic problems are numerous, but in this report it is possible to consider only the questions that directly bear on the occurrence of ore.

The relations of the geology of the peninsula to that of the Ketchikan mining district have been already described (pp. 16–28). The following discussion will be confined to the stratified rocks, which comprise those of sedimentary and volcanic origin; the intrusive rocks, which apparently underlie the peninsula and consist essentially of granitic and porphyritic rocks; and the ore deposits.

The stratified rocks are of interest to the miner because they determine the character and composition of the ore bodies. The intrusive rocks are of even greater interest because they are believed to be the original source of the ores. As the principal ore deposits are found at or near contacts between certain intrusive and stratified rocks, it is desirable to determine the particular intrusive or intruded rocks with which the ore deposits are most commonly associated.

THE GEOLOGIC MAP.

On the geologic map (Pl. XV, in pocket) an attempt has been made to show the distribution of the stratified and intrusive rocks and to indicate the location of the principal known ore bodies. In the field much difficulty was encountered in determining the geologic boundaries and in recognizing the various geologic formations, some of which are remarkably similar. The mountain sides are heavily timbered and the low levels and flats are covered with a dense growth of vegetation, so that exposures of bedrock are rare and are found principally in the stream gulches and at points along the shore. These meager rock exposures afford the only means of indicating the distribution of the various rock formations in the areas that are covered with

vegetation and talus. The geologic sections that accompany the map and show the underground structure of the rock formations are based entirely on inferences from surface observation, except in places where the structure was revealed by mine workings. Future detailed geologic mapping and mining will doubtless disclose many errors in this map, yet the writer believes that it shows with fair accuracy the general distribution of the rock formations and that it may therefore be of use to the miner and to the prospector.

STRATIFIED ROCKS.

CHARACTER AND RELATIONS.

The stratified rocks are principally tuffaceous graywackes interstratified with quartzites, conglomerates, and some limestones. These sedimentary deposits comprise a conformable series of beds several thousand feet thick, all probably of Devonian age. They occur principally in the northern part of the peninsula and have been generally altered by regional and contact metamorphism. It was not possible in the field to subdivide these sediments stratigraphically, so that in this discussion and on the accompanying map they are considered only as to their lithology. Two lithologic types have been recognized in the mapping—(1) a series of clastic rocks, including graywacke, quartzites, and conglomerates, and (2) a series of limestones. The limestones are of the greater economic importance because of the influence they have had on the occurrence of the copper deposits.

Nearly two-thirds of Kasaan Peninsula is occupied by clastic rocks, which in large part consist of a series of metamorphosed sediments, usually epidotized and containing crystals of amphibole or pyroxene. In texture these beds range from fine-grained compact rocks, such as quartzites and graywackes, to coarse conglomerates. As these sedimentary rocks are composed of igneous material, and as they have been greatly altered, they closely resemble massive igneous rocks, though in most places their clastic texture may be recognized, especially on weathered surfaces.

The term Kasaan greenstone was applied to these beds by Brooks in his report on the Ketchikan district in 1901,[1] but detailed study has shown that they are graywackes containing in certain places tuffaceous material. Interstratified with these rocks are narrow beds of limestone, which are entirely recrystallized and contain no traces of organic remains. The relation of these limestone beds to the fossiliferous beds on Long Island, in Kasaan Bay, 1 mile southwest of Kasaan Peninsula, is important and will be discussed later. The stratigraphic succession of these sedimentary rocks is difficult to determine, as the beds are nearly vertical in dip and structurally appear to lie in the form of a synclinorium.

The rocks of this series are described separately, and these descriptions are followed by a discussion of their age and structural features.

GRAYWACKE.

Graywacke is a general term that was used in the field to designate certain obscurely bedded, in places much altered, greenish rocks, which range in texture from distinctly conglomeratic to aphanitic. Some of the finer-grained graywackes can with difficulty be distinguished from igneous rocks. The results of the field study led to the inference that the graywackes consist largely of igneous material worked over mechanically but not greatly decomposed before deposition, and this inference is confirmed by microscopic study. Since their deposition, however, they have been in places greatly changed by shearing, brecciation, and the development of secondary minerals. Some of the most characteristic specimens collected were selected for detailed study. The order in which they are described follows generally their increasing fineness and metamorphism. The degree of metamorphism necessary to convert a certain rock into a graywacke has not been determined or defined, but for those

[1] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of the geology of southeastern Alaska: U. S. Geol. Survey Prof. Paper 1, pp. 49–50, 1902.

specimens studied in thin section in which metamorphism had gone far enough to be readily detected the field name graywacke has been retained. The microscopic examinations and descriptions are the work of H. E. Merwin.

Specimen 129. Graywacke (conglomeratic). The broken surface of this rock has the appearance of an augite lamprophyre; the weathered surface shows bedding and pebbles. In the slide two kinds of pebbles can be made out, one of graywacke, consisting of fragments of augite, hornblende, and feldspar in a dusty chloritic matrix; the other of porphyry, containing large crystals of fresh augite with decomposed feldspar in a groundmass which is chiefly chloritic. Besides pebbles there are angular fragments of porphyry and of minerals derived from porphyry. This angular material and dustlike particles and chlorite form the matrix of the rock.

Specimen 195. Graywacke (conglomerate). In the hand specimens pebbles of porphyritic rocks, the largest several centimeters in diameter, can be distinguished, but their outlines are not clear. Some of these pebbles contain large crystals of hornblende. The thin sections show that the pebbles represent at least five different porphyritic rocks. The matrix consists of fragments of hornblende and feldspar, which are partly chloritized and partly recrystallized as hornblende and epidote. Borders of the secondary hornblende have formed around the original large fragments of hornblende. The rock contains minute veins of secondary hornblende, calcite, epidote, and zoisite.

Specimen 188. Tuff. Megascopically the rock has the appearance of a fine-grained altered hornblende lamprophyre, which contains scattered angular inclusions of a medium-grained leucocratic rock. When moistened the dark parts of the rock also seem to have inclusions. Viewed microscopically the fragmental material appears more angular than that in the rocks already described, and includes abundant broken crystals of hornblende and augite. Much of the matrix is too fine grained for determination. The material as a whole seems to be like that of broken-down but not greatly altered porphyry.

Specimen 196. Graywacke. In the hand specimen this rock looks like basalt, containing minute prisms of hornblende in a much finer grained matrix. Slight magnification of the slide, however, shows clearly the fragmental character of the constituents. Secondary hornblende appears in the matrix and in veins. Epidote accompanies the hornblende in some veins. White mica is the chief alteration product of the feldspar.

Specimen 424. Graywacke. This rock is dark greenish gray mottled with dark red, having a brecciated appearance. The microscope shows that the red patches are fragments of acid porphyries in which phenocrysts of feldspar are contained in a groundmass that is now almost entirely calcite and chlorite. The matrix of the graywacke consists of fragments of feldspar cemented by calcite and chlorite.

Specimen 351. Graywacke. A fresh surface of the rock is dark greenish. The only distinguishable structures are irregular cleavages of hornblende and light aphanitic rounded or subangular patches. A weathered surface is light colored and chalky, with distinct aphanitic patches, the largest 3 centimeters in diameter. Under the microscope the aphanitic material is seen to be aplite, mostly orthoclase, surrounded by hornblende in ragged crystals and granular orthoclase and plagioclase. Epidote and magnetite are abundant. Much of the hornblende appears to be secondary, for the borders of the fragments of aplite are penetrated by the minerals of the matrix.

QUARTZITE.

Prominent beds of quartzite are interstratified with the graywacke. They are of aphanitic texture, are light gray to brown in color, and are highly indurated and brittle. The quartzite at most places contains many cleavage cracks and has a banded structure, which is usually parallel to the main structural lines of the complex. The microscope shows that the quartzite is made up essentially of quartz and a large percentage of feldspar. The rock is an extremely fine textured phase of graywacke, the conglomerates representing the coarse phase.

CONGLOMERATE.

The conglomerate is made up principally of fine to coarse, rounded, waterworn pebbles, though some of the beds contain cobbles and even bowlders. The matrix or cement of this conglomerate is essentially silica and calcite and in certain beds the calcite is most abundant. The pebbles and cobbles are of chert and limestone, those of chert being the more numerous. (See Pl. XVI, *D*.)

LIMESTONE.

Beds of limestone are intercalated with the graywacke and conglomerate. These beds are entirely recrystallized and contain no traces of organic remains. They are of interest because of their association with and relation to the ore deposits, and are indicated separately on the geologic map. They range in thickness from less than 100 to about 600 feet, strike northwestward, and dip to the northeast or to the southwest. At some places the beds are wrinkled and irregularly folded; at others they are brecciated. Dark-colored siliceous beds, from a fraction of an inch to a few inches thick, are interstratified with certain of the limestones, and at some places epidote and garnet have been introduced into the limestones along bedding planes and fractures. (See Pl. XVI, *C*.)

FOSSILIFEROUS LIMESTONES ON LONG ISLAND.

Beds of limestone conformably underlain by feldspathic sandstones and conglomerates occur on Long Island, which is in the central part of Kasaan Bay and lies a mile southwest of Kasaan Peninsula. Interstratified with these limestone beds near their contact with the underlying rocks are narrow beds of sandstone and conglomerate, most of the pebbles in the conglomerate being of porphyry. The limestone beds themselves contain abundant fossils, of Devonian age.

Collections were first made at this locality by A. H. Brooks in 1901. In 1905 a more complete collection was made by E. M. Kindle, who submitted the following report:[1]

> Blue limestones form much of the surface outcrops on a group of small, low islands near the middle of Kasaan Bay, of which Long Island is the largest. On Round Island the limestones are not greatly metamorphosed, but have occupied a zone of vigorous deformational activity. The island affords an uninterrupted outcrop of the limestones entirely around its shore line. These outcrops are of particular interest as illustrating in a small area the complex character of the deformation in this region. The beds are everywhere inclined at a high angle, usually about 90°. On the north and east sides of the island the strike is within a few degrees of due north. From nearly due north the strike swings around abruptly to N. 80° E. on the west side of the island. The exposures on the west side show the sharp elbow which the nearly vertical strata make in changing from a northerly to an easterly strike. The limestone on Round Island is shown by its fossils to be of the same age as the upper beds on Long Island, which lie a few hundred yards southeast.
>
> On Long Island, which has a length of about 2 miles and an average width of less than one-half mile, the limestones show a less degree of deformation than those of Round Island. The flexures have comparatively gentle dips, amounting in parts of the southeastern portion of the island to only 5° or 10°. In the western part of the island, however, the dip rises to 90°. The strike, as on Round Island, varies greatly.
>
> A section along the south side of Long Island from the east end to Salt Pond shows the following series of beds

Section 12, Long Island.

	Feet.
c. Hard dark-gray limestone, slightly darker than the preceding	270
b. Hard blue fine-grained limestone, fracturing easily in any direction	200
a. Buff or cream-colored feldspathic sandstone underlying the limestones	90
	560

> The two divisions of the limestone series are conformable, and the upper and lower portions are very similar in lithologic character. Analyses of the upper and lower portions of the limestone series show them to be very similar in chemical composition, one carrying 96.11 per cent, the other 97.50 per cent of lime.
>
> Aside from the faunal differences, which are quite marked, there are no very evident reasons for making two divisions of the limestones.

[1] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, pp. 47–49, 1908. See also Kindle, E. M., Notes on the Paleozoic faunas and stratigraphy of southeastern Alaska: Jour. Geology, vol. 15, pp. 324–327, 1907.

Fauna.—The character of the fauna in the lower section (*b*) of the limestone series is indicated by the following list:

Stictopora sp.
Cladopora sp.
Spirifer cf. sulcatus Hisinger.
Sanguinolites sp.
Cardiola sp.
Hercynella nobilis Barr.
Hercynella bohemica Barr.
Holopea sp.
Murchisonia angulata Phillips.
Murchisonia sp. 1.
Murchisonia sp. 2.
Planitrochus cf. amicus.
Loxonema sp.
Holopella sp.
Trochonema sp.
Euomphalopteris? sp.
Operculum.
Beyrichia? sp.
Leperditia sp.
Orthoceras sp.

The occurrence of the genus Hercynella in this fauna is of considerable interest, since it has not been found heretofore in America. *H. bohemica* occurs in the Lower Devonian of the Ural Mountains. Both *H. bohemica* and *H. nobilis* are present in étage F of Barrande's Bohemian section. Their presence in the fauna at Long Island indicates that the latter is much more closely related to the European and Asiatic than to the American faunas outside of Alaska. This lower fauna at Long Island represents the lowest Devonian horizon which has been found in Alaska.

In the upper portion of the higher limestone (*c*) the following fauna is found:

Favosites cf. radiciformis Rom.
Cyathophyllum sp.
Orthophyllum? sp.
Zaphrentis sp.
Calceola cf. sandalina.
Syringopora sp.
Lingula cf. bohemica.
Atrypa reticularis Linn.
Atrypa hystrix Hall.
Gypidula opatus (Barr).
Gypidula cf. intervenicus (Barr).
Meristella cf. barrisi Barr.
Stropheodonta stephani (Barr).
Spirifer sp.
Spirifer hians Bich.?
Spirifer thetidis Barr.
Spirifer subcomprimatus Tsch.
Spirifer sp.
Spirifer indeferens Barr.
Spirifer sp.
Reticularia? sp.
Rhynchonella cf. amalthea Barr.
Rhynchonella livonica Buch.
Pugnax sp.
Dalmanella occlusa Barr.
Schizophora macfarlani Meek?
Schizophora striatula Schloth.
Streptorhynchus sp.
Stropheodonta comitans Barr.
Camarotœchia? sp.
Cypricardinia? sp.
Conocardium cf. bohemicum Barr.
Conocardium sp.
Lucinia cf. proavia Goldf.
Leptodesma sp.
Mytilarca sp.
Nuculites sp.
Telinopsis sp.
Holopella? sp.
Loxonema? sp.
Murchisonia sp. 2.
Murchisonia sp. 1.
Naticopsis sp.
Oriostoma sp.
Oriostoma princeps var. Oehlert.
Euomphalus cf. planorbis D'Arch. and Vern.
Tremanotus cf. fortis Barr.
Tentaculites sp.
Ooceras sp.
Gomphoceras? sp.
Orthoceras sp.
Cytherella? sp.
Entomis pelagica Barr.
Lepterditia sp.
Cyphaspis sp.
Proetus sp.
Proetus cf. romanooski Tsch.

In place of the gastropods, which are the dominant forms in the lower horizon, the brachiopods, are the predominant group of this fauna. The Hercynellas, which are abundant at five horizons in the lower beds, appear to be entirely absent. The upper fauna, however, agrees with the lower in its foreign affiliations. In it occurs the peculiar coral, Calceola, very common in the Middle Devonian of Europe. Several specimens among the brachiopods are either identical with or have their nearest analogy in European species. The fauna represents a Middle Devonian or late Lower Devonian horizon.

The lowest 40 feet of division *c* of the Long Island section furnished a fauna differing but slightly from that of the upper part. The following list indicates its character:

Cladopora?
Cyathophyllum sp.
Camarotœchia sp.
Meristella cf. ceres Barr.
Spirifer sp.
Spirifer cf. thetidis Barr.
Spirifer cf. cheiropteryx.
Stropheodonta comitans Barr.
Orthonota sp.
Schizodus sp.
Conocardium cf. bohemicum Barr.
Euomphalus planorbis D'Arch. and Vern.
Oriostoma princeps var. Oehlert.
Tentaculites.
Cyrtoceras sp.
Orthoceras sp.
Proetus cf. romanooski Tsch.

The stratigraphic relations of limestones of Long Island to the geologic horizons represented on the adjacent shore of Kasaan Bay can not be determined because of their topographic isolation.

These limestones are white to gray in color and are noncrystalline. The change from the sandstone to the limestone is abrupt and the limestone occurs only in the upper part of the series. The beds are in general slightly folded, several changes from anticline to syncline having been noted on the shore of the island, the anticlines forming the bays and the synclines the points. Some faults were observed. At a point on the southeast end of the island the limestone lies in contact with sandstone and though the strike was the same the dip was different, suggesting an unconformity. At other points, however, the conformity of the limestones and sandstones was evident.

The structure of the sedimentary rocks exposed on Long Island is of interest because it shows two systems of folding, an older system of small folds with a northeasterly strike and flat dips to the northwest and southeast, and a later system of broader folds which trend northwest and are parallel to the main structural lines of the Coast Range.

AGE OF THE SEDIMENTS.

Though no fossils were found in the limestones on Kasaan Peninsula, the rocks are regarded as Lower Devonian because of the occurrence of fossiliferous limestones on Long Island interstratified with sandstones and conglomerates. Graywackes and conglomerates which correspond somewhat more closely to those of metamorphosed sediments on Kasaan Peninsula are found on the northwest side of Prince of Wales Island and these lie between limestone beds carrying Lower Devonian fossils.

STRUCTURE.

The structure of the stratified rocks on Kasaan Peninsula is that of a closely folded synclinorium in which the beds in general strike northwest and dip northeast. This structure, however, is interrupted locally by masses of intrusive rock, and where these occur the bedding planes of the stratified rocks are usually parallel with the line of contact of the intrusive mass.

Two prominent joint systems were noted on the peninsula, one striking N. 15°–25° E. and dipping 60°–80° SE., and the other striking N. 50°–70° W. and dipping steeply to the northeast. As these joint cracks traverse the ore bodies and country rock alike they were doubtless developed subsequent to ore deposition, and the fact that most of the basalt dikes follow the prominent directions of jointing indicates that the jointing occurred before the basaltic intrusions. Fault planes and gouge seams were noted in the mine workings, and the ore deposits and the dike rocks have here and there been displaced along these planes. The amount of displacement, however, seldom exceeds a few feet.

DETAILS OF OCCURRENCE.

The rocks exposed along the shore north of Hadley are brown to green quartzites containing some amphibole in finely scattered crystals, highly indurated graywackes containing large hornblende crystals embedded in a fine clastic feldspathic groundmass, and gray to green limestones which are locally cherty in appearance. At some places the limestone beds may be regarded as conglomerates with a calcareous groundmass; at others their groundmass is a dark siliceous material. Rounded pebbles of quartzite and white fine-grained limestone are contained in the conglomerate, and in spots the rock is impregnated with epidote and the groundmass is apparently recrystallized. At Lyman Anchorage the graywacke beds are of a fine granular texture, showing microscopic crystals of amphibole, and in places the rock is finely fractured, the cracks being filled with quartz and epidote, and portions of the rock are impregnated with epidote, which gives it a light-green color.

Farther north, at Windfall Harbor, there are beds of argillaceous quartzite altered to phyllite and biotite schist and hornfels, the alteration being partly due to adjacent intrusive masses. At Palmer Cove the graywackes are much altered and epidotized and intruded by granitic rocks. Veinlets of feldspar, quartz, and epidote are prominent along jointing planes in these rocks.

The rocks exposed on the south arm of Thorne Bay consist largely of fine to coarse conglomerates, which are in places much brecciated, so that their sedimentary nature is disguised. The pebbles and cobbles of these conglomerates consist of graywackes, usually somewhat epidotized and containing hornblende crystals, and of porphyry, chert, and limestone. The rocks at this locality are somewhat less metamorphosed than at other points nearer the intrusive masses.

The graywackes along Tolstoi Creek are more brownish and the conglomerates contain brownish fragments of a slaty rock. These beds are also less altered than the graywackes near the intrusive contacts and are not impregnated with epidote, feldspar, and quartz. The limestones also show less effect of metamorphic action.

The rocks exposed on the west side of the peninsula are essentially graywacke and occasional beds of conglomerate, striking in general northwestward and dipping northeastward. Many of the exposures of the graywacke resemble those of a diorite intrusive mass because of their content of hornblende crystals. Their clastic texture and sedimentary origin were, however, evident on weathered surfaces, especially where the graywacke graded into the coarser phase or conglomerate, and they contained limestone pebbles.

At the Rush & Brown mine the rocks grade from a quartzite of banded aphanitic texture to a graywacke and coarse conglomerate. The conglomerate is highly epidotized and the matrix contains hornblende pyrite. (See Pl. XVI, *D*.) Most of the pebbles are of graywacke, porphyry, and limestone. The graywacke is also somewhat epidotized, especially along cracks. At the Venus claim, 1 mile south of the Rush & Brown mine, beds of conglomerate are interstratified with banded slates and graywackes. The conglomerate contains cobbles of quartzite, slate, limestone, and porphyritic rocks with quartz phenocrysts. The graywackes in general show a slight development of hornblende crystals and contain numerous slaty fragments, though in certain areas where metamorphism was apparently greater the slaty fragments are almost absent and the crystals of hornblende are more abundant. These conditions suggest intense metasomatic action in these somewhat porous rock beds, though the development of schistosity which usually accompanies such metasomatic action is lacking, probably because of the resistance of the rock to differential pressure.

At the Copper Center mine the graywacke is much epidotized and contains large crystals of hornblende associated with chalcopyrite. At the Charles prospect the graywacke and conglomerate grade into the contact rock, and masses of conglomerate are surrounded by the contact rock. A similar alteration of the graywacke is evident at the Brown & Metzdorf prospect, where an ore deposit in the contact rock occurs between a limestone bed and graywacke, showing a replacement of both graywacke and limestone. In all these places the rocks are highly metamorphosed, contain much hornblende, and are impregnated with epidote. The occurrences of contact rock at these prospects indicate the proximity of intrusive rock, which was not exposed on the surface, though its presence is indicated on the map in adjacent areas.

The alteration of the limestone is especially evident along the shore just north of Kasaan, where it is much wrinkled, recrystallized, and has a banded structure. The bands are composed of quartz and epidote and veinlets of epidote and garnet, which protrude on weathered surfaces between the bedding planes, showing still further the alteration of the rocks by mineralizing solutions.

INTRUSIVE ROCKS.

OCCURRENCE AND CHARACTER.

The intrusive rocks that apparently underlie Kasaan Peninsula occupy about one-third of its surface. They invade all the sedimentary strata and are therefore more recent than these stratified rocks. (See map, Pl. XV.) They vary in composition from acidic granite and pegmatite to basic diorite and basalt, and in texture from coarse granular to fine porphyritic rocks. They occur in the form of huge intrusive batholiths, many miles in width, and in dikes, the smallest less than a foot wide. The larger masses are longest from northwest to southeast, parallel with the lines of folding of the stratified rocks. The principal intrusive

rock is a diorite, which forms the entire southern part of the peninsula and occupies large areas in its central and northwestern parts. No intrusive rocks earlier than the diorites have been recognized in this region.

Pegmatite dikes intrude the diorites and adjacent metamorphic rocks but are not plentiful. In composition they are nearly like the diorites and were probably derived from the same magma. Porphyritic rocks in the form of dikes, some a few hundred feet wide, also invaded the stratified rocks. The most recent intrusives are numerous small basalt and diabase dikes, which crosscut all the rock formations and the ore bodies.

The intrusive bodies, especially the granitic rocks, are of interest to the prospector, for the principal ore deposits lie at the contacts of the intrusive and the country rock. The main intrusive masses on the peninsula are commonly called granites, though they correspond more closely in composition to diorites. Like the intrusives of the Coast Range, however, this granitic rock varies in composition from a granite to a gabbro, including also syenite, though most of it is diorite.

GRANITIC ROCKS.

GENERAL CHARACTER.

The granitic intrusives include diorite, gabbro, syenite, and a little granite. These intrusives differ considerably in mineral composition and probably represent several periods of igneous invasion during one general epoch, though some of the differences can undoubtedly be attributed to segregation of minerals within the igneous magma while it was becoming solidified.

At the contacts of these granitic batholiths with the country rock there are masses of slightly altered and locally sheared diorite surrounded by unaltered diorite. At some places these masses show sharp contacts, though at others the two kinds of rock merge gradually into each other, suggesting a peripheral solidification of the igneous batholith, a fracturing of its outer part, and subsequent injection of molten rock into the interstices. The igneous mass includes, here and there, angular fragments of highly metamorphosed stratified rocks, some of which can be recognized as included metamorphic rock only because parts of them show parallel lines of flakes of biotite, the remainder of the inclusions having been dissolved by the intruding magma. The schist near the contact also includes, along the bedding planes, feldspar, quartz, and other pegmatitic minerals, suggesting a partial replacement of the intruded beds by igneous material.

DIORITE.

The main intrusive rock of Kasaan Peninsula is a quartz-bearing diorite. The quartz is scarcely more than an accessory, generally forming not more than 5 per cent of the mass. Orthoclase appears in about the same amount. Plagioclase, which makes up 50 to 70 per cent of the rock, is basic andesine, ranging chiefly from Ab_3An_2 to Ab_1An_1. The range of the composition of the individual plagioclase crystals is about the same. For this reason zoning is not pronounced. Twinning according to both the albite and the Carlsbad laws is very common in the plagioclase. Hornblende is everywhere present, constituting 10 to 35 per cent of the weight of the rock. It is the common variety; it is pleochroic in various yellow-greens; it is optically negative, showing a large optic axial angle; its maximum extinction angle, measured from the trace of the cleavage, is from 20° to 25°, corresponding to an angle of 15° to 20° on (010); and its indices of refraction are considerably higher than those of other recorded measurements, namely from 1.665 to 1.680, determined by the immersion method. Some facies of the diorite contain about 15 per cent of yellow-brown or orange-brown biotite. The rock contains small amounts of augite, less than 10 per cent. The minor accessories are apatite, titanite, and magnetite.

The mineral composition, summarized from a study of 16 slides made of rock taken from different parts of the peninsula, shows that the rock contains too little quartz and orthoclase and that its plagioclase contains too much lime to justify its classification with the granodiorite that is so common on the Pacific slope of North America. According to Lindgren [1] this grano-

[1] Lindgren, Waldemar, Granodiorite and other intermediate rocks: Am. Jour. Sci., 4th ser., vol. 9, pp. 269–282.

diorite contains an average of about 23 per cent of quartz, 14 per cent of orthoclase, and 44 per cent of plagioclase (near Ab_2An_1).

Some of the extreme types of the diorites of Kasaan Peninsula are described below. The numbers refer to slides and specimens in the collection of the United States Geological Survey, the full catalogue designation bearing the prefix "7. C. W."

173. Hornblende diorite, from about 4 miles northwest of Hadley. In hand specimen the rock is seen to consist megascopically of plagioclase, hornblende, quartz, magnetite, pyrite, and titanite in a medium-grained groundmass, the bulk of the crystals being between 1 millimeter and 5 millimeters in diameter.

The microscope shows that the rock contains about 55 per cent of plagioclase (Ab_1An_1), 35 per cent of hornblende, 5 per cent of quartz in poikilitic masses, and 5 per cent of accessory magnetite, apatite, biotite, and titanite. In the main the order of crystallization was plagioclase, magnetite, hornblende, and quartz.

135. Hornblende diorite, from the southeastern point of Kasaan Peninsula. Although this is mainly a medium-grained granitic rock, it appears coarse grained on account of its large content of poikilitic masses of hornblende and plagioclase.

Under the microscope the plagioclase, which makes up 60 to 70 per cent of the rock, is found to be about Ab_3An_2. Hornblende, which forms about 25 per cent of the rock, occurs partly in prisms among the feldspar and partly in poikilitic masses inclosing plagioclase. The prisms of hornblende are much lighter in color than the poikilitic masses. Quartz and microcline are very subordinate constituents.

199. Hornblende diorite of medium-grain granitic texture, from a large intrusive mass in the northern part of the peninsula. In the slide the following minerals are found in about the proportions stated: Basic andesine, 70 per cent; hornblende, 15 to 20 per cent; quartz, 5 to 10 per cent; biotite, 5 per cent; accessories, 3 to 5 per cent. Near the contact this rock (specimen 201a) contains phenocrysts of hornblende and plagioclase, the hornblende in many places having nuclei of corroded augite. Augite is very much more abundant in parts of this diorite that have cooled more rapidly than the main body of the intrusive, and particularly in the diorite porphyries to be described later.

106. Biotite diorite of medium grain, from a point near the central part of the peninsula. It contains about 60 per cent of plagioclase (Ab_2An_2), 5 per cent of orthoclase, and 35 per cent of dark minerals, of which biotite is somewhat more abundant than either of the other two essential constituents, hornblende and augite. Magnetite is intergrown with the augite.

GABBRO.

Near some of its margins the diorite becomes basic and passes into gabbro, the hornblende giving place to augite, and the plagioclase becoming richer in lime. Specimens from the mines and prospects north of Karta Bay illustrate this transition.

411. Augite gabbro lamprophyre. This is a melanocratic, porphyritic, medium to coarse grained rock, containing phenocrysts of augite, the larger bordered with primary hornblende and uralite. Many of the smaller phenocrysts are chloritized on the outside and serpentinized within. The groundmass consists of plagioclase (Ab_2An_3), common hornblende, and biotite. Both hornblende and biotite are in part later than the feldspar. The accessories, which crystallized early, are iron ores, apatite, and titanite.

254. Augite gabbro. In the hand specimen this rock is nearly black, medium or fine grained, granitic, and contains visible augite, magnetite, and biotite.

In the thin section the augite is seen to be hypidiomorphic, the distinctly pleochroic grains constituting about 55 per cent of the rock mass. A strongly pleochroic yellow-brown biotite makes up about 25 per cent of the rock and iron ores, in part later than the pyroxene, form 10 to 15 per cent. The biotite is later than both the augite and the magnetite. The spaces among these minerals are filled with much-altered plagioclase. A rock similar to this (specimen 246), much brecciated and impregnated with bornite and chalcocite, is worked as an ore of copper.

SYENITE.[1]

Most of the syenitic rocks occur in dikes and are of porphyritic texture. They are therefore described under the heading "Porphyritic intrusives" (p. 77). Syenite occurs, however, in batholithic masses, principally as a differentiation product of the dioritic magma. The rock shows a preponderance of soda over potassium, as would be expected in a rock derived from a dioritic magma.

43. Albite syenite, from a dike near the head of Hole in the Wall. This is a fine-grained granitic rock, ranging in color from gray-green to red. Its chief mineral is nearly pure albite showing a maximum extinction angle of 16°. The minor constituents are orthoclase (15 to 20 per cent) and biotite (about 10 per cent). Apatite, titanite, and magnetite are accessories, apatite being especially abundant. Although the texture of the rock is granitic, the biotite was in part the last product of crystallization. The rock contains scattered grains of primary calcite and veinlets of secondary calcite.

116. Albite syenite, from a point 1½ miles southeast of Boggs Landing. This type is a light-greenish aphanitic rock that shows in the thin section a fine-grained granitic texture. About 90 per cent of it is albite having a mean refractive index of about 1.530, showing the presence of about 15 per cent of dissolved orthoclase. The rock contains about 10 per cent of quartz but little or no ferromagnesian minerals. This rock and No. 259 are the most alkalic rocks collected from Kasaan Peninsula.

GRANITE.

A second phase of the differentiated diorite magma consists of rocks rich in both alkali feldspars and quartz. Between these rocks and the highly alkalic rocks previously described there are transitional forms, such as the first of the types described below. The more quartzose rocks are in general later and smaller in bulk than the highly feldspathic rocks.

64. Soda granite, from one of the longest granite masses, about 4 miles south of Hadley. This rock is light greenish gray, is medium grained, and consists of visible quartz, plagioclase, and biotite.

In the thin section the proportions of the minerals are seen to be about as follows: Albite, 70 per cent; quartz, 20 per cent; biotite, 10 per cent. The composition of the albite is about $Ab_{15}An_1$, as shown by its refractive index and extinction angle. The accessory minerals are apatite and magnetite.

396. Soda granite, from a dike north of Karta Bay. A light greenish-gray and medium-grained granitic rock. The minerals distinguishable in the hand specimen are quartz, plagioclase, chlorite, epidote, magnetite, and pyrite.

In the thin section the quartz (25 to 30 per cent) is mainly interstitial. The plagioclase has the optic properties of nearly pure albite. These two minerals make up about 98 per cent of the rock. The chlorite is derived from biotite, and epidote has come from the small amount of lime-bearing plagioclase.

39. A medium to coarse grained red granite from a point 1 mile north of Hadley, consisting almost exclusively of light-colored constituents, perthitic orthoclase, and quartz in about equal amounts. The dark constituent is biotite. This is the most acidic intrusive rock collected from the peninsula.

DETAILS OF OCCURRENCE.

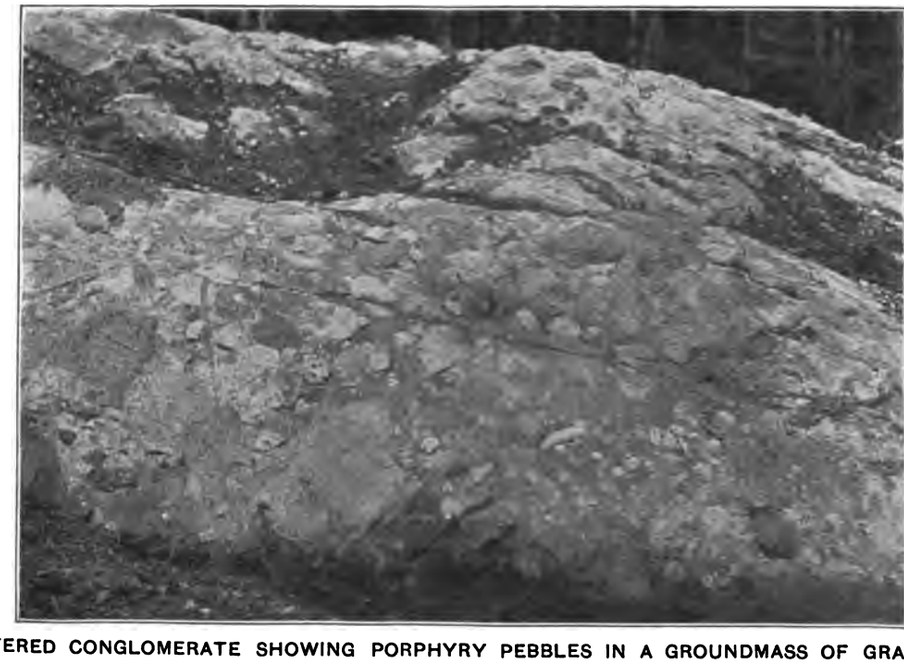
The granitic intrusives which compose Grindall Island, at the southeast end of Kasaan Peninsula, are much segregated and fractured. The segregations are essentially masses of basic hornblende locally showing radiating crystals of hornblende a few inches in length. In places the rock grades from coarse-grained to fine-grained diorite within a short space and at other places it appears to have been fractured and the fractures, most of them rather wide, filled with diorite of fine or coarse texture. At certain points a gneissoid banding or flow structure was noted in the intrusive mass and between the bands are irregular masses of a coarse basic

[1] Petrographic microscopic descriptions by H. E. Merwin.

A. DIORITE ON SOUTH SIDE OF LYMAN ANCHORAGE NEAR CONTACT WITH KASAAN FORMATION.
The diorite shows parallel arrangement of the feldspar, indicating flow structure.

B. DIORITE ONE-HALF MILE SOUTH OF LYMAN ANCHORAGE.
An aplite dike (of lighter shade in view) cuts the diorite and is faulted along a joint plane.

C. LIMESTONE ON SHORE 1 MILE SOUTHEAST OF LYMAN ANCHORAGE.
The beds of limestone are in places metamorphosed and traversed by small dikes of basalt.



D. ALTERED CONGLOMERATE SHOWING PORPHYRY PEBBLES IN A GROUNDMASS OF GRAYWACKE.
View taken at Rush & Brown mine.

diorite a foot or more in diameter. These phenomena near the contact of the largest intrusive mass on Kasaan Peninsula seem to show that there was a lack of uniformity in the composition of the original magma at the time of its intrusion and that after the first intrusion and consolidation fracturing occurred and additional magma was forced into the fractures. A further consolidation, accompanied by fracturing and by the introduction of magmatic solutions, may account for the pegmatitic and aplite and alaskite dikes which are most common in the granitic rocks near the contact. (Pl. XVI, *A*, *B*.)

At Lyman Anchorage the granitic intrusive at the contact is gneissoid, the structure striking N. 20° E. and the dip being vertical, parallel to the contact. This dioritic rock is cut by veins and dikes, the largest 100 feet wide, of orthoclase quartz pegmatites or alaskites, and some of the veins grade into quartz veinlets a few inches thick. Most of the minerals in these dikes and veins are coarsely crystalline. At the contact the intruded rocks have been altered to an amphibole schist, so that the line between the intrusive and intruded rock is not always clearly defined. A short distance away from the contact the intrusive rock is diorite of uniform texture, though it contains inclusions of basic diorite and amphibolite. These inclusions as well as the diorite some distance from the contact are cut by the pegmatitic dikes.

The main diorite mass on Tolstoi Mountain, at the north end of Kasaan Peninsula, is almost identical in composition and character with that at Grindall Point, and around its contact similar phenomena were observed. A typical specimen (No. 199) from Tolstoi Mountain has already been described (p. 75).

The gabbro is limited to the mass that includes the Goodro mine and extends northwestward beyond the Rush & Brown mine, but only part of this mass is actually gabbro. The western part of this intrusive mass, which is indicated on the map (Pl. XV), is made up of normal diorite. The eastern part of the mass is a coarsely crystalline augite gabbro (see descriptions of specimens 411 and 254, p. 75), sufficiently rich in magnetite to deflect the compass. At the Goodro mine the gabbro is cut by dikes of diorite and pegmatite, so the gabbro is somewhat older than the diorite. Both the gabbro and diorite are altered in places and contain epidote and calcite. At this mine a great number of dikes and veins of feldspar and quartz, many of them containing coarse crystals of amphibole, lie near the ore body.

Near the Rush & Brown mine the diorite contains numerous inclusions of the gabbro, which is therefore the older. Here also the gabbro and diorite are cut by dikes and veins of pegmatite and have been somewhat altered by the mineralizing solutions that deposited the epidote, calcite, and pyrite.

Granitic intrusive of the syenite type was found near the contact of the large intrusive mass at Boggs Landing. Granitic intrusive having a porphyritic texture occurs in large dikes and is described under the heading "Porphyritic intrusives" (below). At many places syenite forms a part of the granitic intrusive masses near their contacts and is merely a phase of the general dioritic mass. The syenite, however, contains inclusions of diorite and fills fractures in the diorite and is therefore regarded as of somewhat later intrusion that the diorite, though in all other features the two types of rock are identical.

The granites, which are also regarded as a phase of the dioritic intrusives, are similar in occurrence to the syenites. At a point 4 miles southeast of Hadley there is a mass of granite nearly half a mile wide, and at a point a mile northwest of Hadley, at the contact of a large mass of diorite, there is a similar granitic mass. A third and larger mass of granite lies north of Karta Bay. The rock of this mass, however, is rich in plagioclase and approaches a quartz diorite in composition. The features of the occurrence of these granitic masses are the same as those of the diorite.

PORPHYRITIC INTRUSIVES.

GENERAL CHARACTER AND DISTRIBUTION.

In general the porphyritic rocks occur in the form of dikes that are from 10 to 100 feet wide and stand nearly vertical. Most of these dikes strike north to northwest but some strike nearly east. In color the porphyries are greenish to pinkish and generally show well-developed

though closely crowded feldspar crystals. The phenocrysts are principally plagioclase feldspar and augite or hornblende, the groundmass being microgranular and made up essentially of feldspar and some quartz. The porphyries are generally of syenite, those of granite diorite being scarcer. Ore deposits occur at the contacts of some of the larger porphyry dikes, and although most of them are commercially unimportant they are of geologic interest and are described under the heading "Copper ores" (p. 85). The distribution of the porphyries is shown on the geologic map (Pl. XV).

DIORITE PORPHYRIES.

It was not generally possible in the field to distinguish the diorite porphyries from the related syenite porphyries. In fact, the diorite porphyries form a transitional group between the diorite, the syenite porphyries, and the granite porphyries.

In these porphyries quartz, orthoclase, and augite are more abundant than in the diorite, and the plagioclase is more sodic. Some of the diorite porphyry dikes are more basic near the contact. A dike 60 feet wide, on the east side of Tolstoi Bay, contains in its central part about 40 per cent of hornblende, which is mostly in phenocrysts associated with plagioclase but is partly in the groundmass with about equal amounts of quartz, orthoclase, and plagioclase (specimen 222). A specimen taken near the contact (specimen 223) contains about 65 per cent of hornblende, mostly in the fine-grained groundmass.

But few of the specimens of diorite porphyry examined were fresh enough to warrant more definite statements concerning their original mineral composition than have already been made. The two specimens described below, taken from places near the coast about one-fourth of a mile west of Hadley, are comparatively fresh.

Specimen 46. Augite diorite porphyry. The hand specimen is a dark-gray medium-grained porphyritic rock with abundant phenocrysts of plagioclase and augite, the augite presenting many glistening cleavage surfaces and crystal faces.

In the thin section the plagioclase is seen to be twinned according to both the Carlsbad and albite laws, and its composition was determined as about Ab_1An_2. The augite phenocrysts are in part glassy, clear, and faintly colored, and are in part uralitized. Some augite crystals are surrounded by primary hornblende. The groundmass consists of plagioclase, augite, hornblende, biotite, orthoclase, and quartz. Orthoclase is intergrown with quartz. Apatite and magnetite are abundant, the apatite forming numerous trellis-like structures composed of long, slender needles, structures so frail that it is difficult to understand how they could have been preserved while the rock was in process of solidification. The plagioclase forms about 50 per cent of the rock, and the dark constituents 35 per cent.

Specimen 48. Diorite granophyre. This is a dark reddish-gray rock, fine grained and porphyritic. The phenocrysts are strongly zoned plagioclase, ranging in composition from basic andesine through oligoclase, the interiors being most calcic. The groundmass consists essentially of plagioclase, quartz, and orthoclase, the last two minerals being intergrown as micropegmatite. Quartz and orthoclase occupy about 25 per cent of the area of the slide; dark silicates, hornblende, and biotite, less than 10 per cent. Magnetite, titanite, and apatite are accessories.

SYENITE PORPHYRIES.

Most of the syenitic rocks are of porphyritic texture, but some are granitic. They occur in dikes and contain the highly alkalic differentiation products of the diorite magma. These alkali rocks form a series that stands between two extreme types, one highly potassic, the other highly sodic. The mass of the sodic type is much the greater, judging from the relative abundance of the specimens of the two types collected. Soda should preponderate in the syenites on account of the relatively high soda content of the diorite from which they were derived.

Specimen 259. Calcite syenite porphyry, from a dike near the head of Karta Bay.

In the hand specimen the rock is light yellowish gray, fine grained, and porphyritic. Equidimensional phenocrysts of faintly greenish feldspar about 3 millimeters in diameter form about 2 per cent of the rock; other phenocrysts of rhombic habit, about 0.5 millimeter in diameter, make up a larger percentage. On weathered parts of the rock the phenocrysts have

been dissolved and the cavities filled with limonite. The phenocrysts effervesce freely in hot dilute hydrochloric acid, and therefore appear to be ferruginous calcite. Weathered surfaces of the rock are chocolate-colored, and broken surfaces of weathered parts are light brown specked with dark brown.

In the thin section the rock is seen to be holocrystalline. The phenocrysts of feldspar have symmetric extinction angles of albite twins as high as 16°, and refractive indices of about $\alpha = 1.529$, $\gamma = 1.537$. These angles and refractive indices point to albite. The borders of the phenocrysts show the effects of resorption and subsequent renewed growth. The latest material appears to have been crystallized contemporaneously with the groundmass, as shown by interpenetration. The calcite phenocrysts occur as euhedral crystals, having the habit of the unit rhombohedron. By a geometric analysis of three slides these crystals were found to make up 3 to 6 per cent of the rock mass. Small calcite rhombs are included in the albite phenocrysts, showing that the calcite was the earliest of the essential constituents to crystallize. The refractive index ω of the calcite is 1.742 ± 0.003. For pure calcite $\omega = 1.658+$. The high refractive index of the phenocrysts must be due to the presence of siderite.

The groundmass consists of sheaf-like aggregates of finely fibrous feldspar. A few of the coarser fibers, possibly phenocrysts, exhibit albite twinning and an observed maximum symmetric extinction of 17°. The refractive indices α and γ are 1.524 and 1.531. From these facts alone it would be difficult to decide whether the feldspar should be considered as soda orthoclase or as a potash-rich albite. Too little is known of the relation between chemical composition and the refractive index of the soda-potash feldspar to make one the basis for estimating the other. No feldspar of lower refractive index was found in the slides. Interstitial quartz occurs in small isolated patches and probably as thin films among the feldspars. Its bulk is estimated at 5 per cent or less. From 2½ to 3 per cent of calcite is scattered through the groundmass in minute rhombs, either singly or clustered. The accessory minerals, each amounting to less than 1 per cent, are muscovite, apatite, possibly zircon, and a fibrous mineral having the general optic properties of a yellow-green amphibole.

An analysis of this rock by R. C. Wells has been calculated into normative minerals according to the methods of the quantitative system, except that, the lime being insufficient to combine with the CO_2 to form calcite, FeO was used to form siderite. In classifying the rock siderite was grouped with calcite.

The ratio of calcite to siderite calculated from the analysis is lower than would be inferred from the refractive index of the calcite phenocrysts. It is possible that the small rhombs of calcite in the groundmass are richer in iron than the phenocrysts.

Chemically and texturally the rock is a distinctly new type. Chemically, however, it can be made to conform to the quantitative system of classification by changing the method of calculating the minerals as described above. Texturally, the occurrence of calcite in euhedral crystals in an igneous rock is unique. There can scarcely be any doubt that the calcite crystallized directly from the magma. According to Adams and Barlow,[1] primary calcite has been found in granular form in igneous rock. The rocks described by them do not contain free silica, as this rock does.

Analysis of calcite syenite porphyry.

[By R. C. Wells.]

SiO_2	63.41	ZrO_2	0.04
Al_2O_3	16.86	CO_2	2.93
Fe_2O_3	None.	P_2O_5	.12
FeO	2.88	SO_3	None.
MgO	Trace.	Cl	None.
CaO	1.47	S	.05
Na_2O	7.38	MnO	.28
K_2O	3.09	BaO	None.
H_2O-	.29		
H_2O+	.42		99.48
TiO_2	.26		

[1] Adams, F. D., and Barlow, A. E., Geology of the Haliburton and Bancroft areas, Ontario: Geol. Survey Canada, Mem. 6.

Calculated mineral composition.

Corundum	1.06	Apatite	0.34
Quartz	8.74	Rutile	.26
Orthoclase	18.35	Water	.71
Albite	62.35		
Calcite	2.30		99.21
Siderite	5.10		

This calculated composition corresponds to nordmarkose.

Specimen 291. Augite trachyte, from a point near the head of Karta Bay. This is a greenish-gray medium-grained porphyritic rock containing abundant tabular phenocrysts of orthoclase arranged in flow structure. Augite forms phenocrysts and is a chief constituent of the groundmass. Magnetite is easily recognized by means of a lens.

Under the microscope the orthoclase phenocrysts appear to make up about 50 per cent of the mass of the rock. They are fresh and almost glassy, much resorbed, and hold inclusions of augite, plagioclase, and magnetite. One slender crystal is bent in an arc of 9°. The bending has not caused perceptible fracture, but the positions of extinction instead of being turned 9° are turned 13° on the convex side and 6° on the concave side of the crystal. From determinations of the refractive indices of the orthoclase (made by methods based on immersion) it appears to be a nearly pure potash feldspar ($\alpha = 1.517 \pm 0.001, \gamma = 1.525 \pm 0.001$). The extinction on 010 is 7° and the optic axial angle near the maximum for orthoclase. Augite in crystals of various sizes makes up about 30 per cent of the mass of the rock. Biotite that is altered to chlorite and some epidote, a very minor constituent, were formed later than the augite and orthoclase. The groundmass consists of almost completely altered plagioclase, the crystals having been originally not much smaller than those of the phenocrysts. Muscovite and epidote are the chief present constituents of the groundmass. The freshness of the orthoclase and augite and the very far advanced alteration of the plagioclase and biotite are remarkable. All the observed extinction angles of the plagioclase were less than 13°, so that it is nearly pure albite.

Syenite lamprophyre dikes, consisting largely of ferromagnesian minerals with subordinate alkali feldspars, were intruded at the same general period as the syenites. Such dike rocks bear the same relation to the syenites that the gabbros bear to the diorite, with the exception that the gabbros consolidated as marginal facies of the diorite, where they had accumulated during differentiation. While the gabbros were in process of consolidation the forces that caused fissuring were not strongly active, but while the lamprophyres were consolidating these forces must have been nearly at their period of greatest activity. Specimen 108, from a dike cutting albite syenite, contains about 40 per cent of augite in phenocrysts, 15 per cent of hornblende, 10 to 15 per cent of chlorite, a little calcite, and 30 per cent of albite. Specimen 250 contains about 70 per cent of ferromagnesian minerals (now chiefly uralite and epidote) and 30 per cent of orthoclase.

GRANITE PORPHYRIES.

35. Quartz porphyry, from a dike about 2 miles northwest of Hadley. This rock is nearly white and translucent, containing scattered phenocrysts of quartz in a very fine grained groundmass of plagioclase, quartz, and muscovite. The phenocrysts have been considerably resorbed.

769. Granophyre, a dark-red fine-grained rock from a dike in Stevenstown tunnel. A first generation of albite in scattered crystals was followed by a second generation of albite in abundant idiomorphic crystals. The groundmass is micropegmatitic, quartz being intergrown with both orthoclase and plagioclase. Muscovite, biotite, and hornblende are accessories. Primary calcite appears in this rock in two forms, first, as an early crystallization in distinct rhombs included in the albite; second, in interstitial intergrowth with quartz as a final crystallization.

AGE OF THE PORPHYRIES.

The porphyries are presumably younger than the granitic intrusives because of their relation to these intrusives in composition and occurrence. The syenite porphyries at least

are older than the ore deposits, for many of the contact ore bodies lie at their contact. Such ore deposits were not noted at the contact of the diorite porphyry dikes, which crosscut the syenite porphyries and hence are younger than the syenites.

PEGMATITES, ALASKITES, AND APLITES.

GENERAL FEATURES.

Dike or vein rocks that are made up essentially of feldspar and quartz—such as the pegmatites, aplites, and alaskites—are not plentiful on Kasaan Peninsula and are found only at places near the periphery of the large granitic intrusive masses. At these places such dikes cut both the large intrusive masses and the intruded sedimentary rocks. They occupy narrow seams and large fissures and strike in various directions, following no particular systems of fracturing. In mineral composition these rocks consist essentially of orthoclase, some albite, and quartz. The coarsely crystalline types are known as alaskites and pegmatites, whereas the fine-grained rocks of practically the same composition are called aplites. Only two specimens of these rocks, representing a somewhat peculiar type, are described here.

PETROGRAPHIC DETAIL.

Specimen 137. Calcite alaskite aplite, a fine-grained light-pink rock, when examined microscopically, was found to consist of about 60 per cent of orthoclase, 30 per cent of quartz, 9 per cent of primary calcite, and a little plagioclase. The red color of the rock is due to dusty hematite sprinkled through the feldspar. The rock is very fresh. (See Pl. XVII, *C*, *D*.)

Two periods of crystallization can be made out. In the first period quartz, orthoclase, and a little calcite formed an even-grained mass penetrated by spider-like stringers of the mother liquor. In the second, the mother liquor solidified in a partly granular, partly poikilitic mass. Orthoclase and calcite are much more abundant in the later crystallization, and the calcite is coarser grained and anhedral.

The proportion of orthoclase to plagioclase is much greater in this rock than in any other examined.

Specimen 767. Alaskite aplite. This rock, taken from a dike 1 inch wide in the Stevenstown tunnel, contains 10 to 15 per cent of albite, 40 to 50 per cent of orthoclase and microcline, and 30 to 35 per cent of quartz. The dike cuts syenite. From the broken phenocrysts in the syenite parallel growth of feldspar has taken place in the dike, indicating that the temperature of the dike was not very different from the temperature of the syenite when the dike was intruded. The feldspar of the syenite is considerably altered by weathering, but that of the dike is still fresh. It is this difference in alteration that makes it possible to trace the boundary of the dike through optically continuous crystals.

AGE.

Their composition and their mode of occurrence as fillings of small and wide cracks having various courses, in both the intrusive and intruded rocks, suggest, as has often been pointed out by geologists, that the magma which formed these dike rocks was injected soon after the intrusion of the diorites and that the fissures they fill are contraction cracks caused by the shrinkage that accompanied the cooling and crystallization of the igneous intrusive masses.

The rocks of this group are assumed to have been derived from the same magma that furnished the granitic intrusives and to have been formed from aqueo-igneous solutions that contained more water than the diorite magma.

The age of the pegmatite and aplite as compared with that of the porphyries is not shown by intersection, but the intimate relations of the granitic intrusives to the pegmatite and aplite when compared with the relations of these intrusives to the porphyries show that the porphyries are younger than either the granitic intrusives or the pegmatites and aplites.

45925°—15——6

PLATE XVII.

A, *B*. Microscopic views of alaskite aplite (specimen 767, see p. 81). *A*, Section showing contact of an alaskite aplite dike (lighter area) with syenite. *B*, Same section under crossed nicols, showing optical continuity between the crystals of microcline (*a*) and of orthoclase (*b*) in the syenite and the aplite. Dotted line indicates line of contact.

C, *D*. Microscopic views of calcite alaskite aplite (specimen 137, see p. 81). *C*, View under crossed nicols, showing texture. Early crystallization is indicated by the coarse granular texture and later crystallization by the areas of calcite (outlined) and the fine-grained texture. *D*, Same section without nicols crossed, showing areas of calcite.

THIN SECTIONS OF ALASKITE-APLITE AND CALCITE-ALASKITE FROM KASAAN PENINSULA.

CONTACT ROCK.

GENERAL FEATURES.

The name "contact rock" is applied to the metamorphic rock that occurs in zones around the granitic intrusive masses and that has at many localities replaced the granitic rock. In composition it consists mainly of garnet, diopside, and feldspar, but it contains also hornblende and tremolite and some calcite. It includes masses and disseminated particles of sulphide minerals and masses of magnetite containing sulphide ores. A sample of this rock (specimen M1) taken for chemical analysis is described below.

PETROGRAPHIC DETAIL.

Specimen M1. Rock from contact zone between the limestone and the intrusive rock at the Mamie mine, 1¼ miles south of Hadley.

The chemical analysis, made by George Steiger, shows that this rock has the composition of a monzonite rich in lime. The intrusive rock at the Mamie mine goes under the field name of syenite, but an examination of six thin sections from several drill cores of the partly altered intrusive rock shows that considerably less than half the feldspar is orthoclase and that the plagioclase is basic oligoclase and acidic andesine. The rock contains also a small amount of quartz. The ferromagnesian minerals are much subordinate to the feldspar. The mineral composition therefore shows that the rock is a monzonite, and that it is part of the intrusive mass. Its slightly higher content of lime than most monzonites is probably due to lime brought in from the adjacent limestone.

The rock consists of about 50 to 60 per cent of plagioclase (albite and oligoclase), 10 per cent of orthoclase, 20 per cent of epidote, and 10 to 15 per cent of calcite. It contains also a lath-shaped mineral, confined chiefly to secondary veinlets, which is somewhat unlike ordinary rock-making minerals. Its index of refraction ranges from 1.58 to 1.625, its optic axial angle is large, optical character positive, birefringence rather strong, extinction parallel or nearly so, and elongation positive. These characters agree very well with pectolite or prehnite.

In the hand specimen the rock is greenish gray in color and aphanitic.

Analyses of monzonites from Kasaan Peninsula, Alaska (A), and from Babcock Peak, Colo. (B).

[Analysis A by George Steiger; B by H. N. Stokes.]

	A	B		A	B
SiO_2	58.87	57.42	TiO_2	0.59	0.86
Al_2O_3	17.12	13.48	CO_2	.84	None.
Fe_2O_3	1.96	3.74	P_2O_5	.20	.36
FeO	.95	2.10	Cl		.03
MgO	1.75	1.71	S	.09	None.
CaO	8.00	6.84	MnO	.10	.09
Na_2O	4.64	4.52	BaO	.06	.15
K_2O	4.34	3.71	SrO	.02	.08
H_2O-	.13	.28	Li_2O		Trace
H_2O+	.81	.08			

DIABASES AND BASALTS.

GENERAL CHARACTER.

The more basic intrusive rocks, as well as the most recent, are essentially diabase and basalt. These rocks form dikes that range in width from 1 foot to many feet, in texture from microgranular to coarse granular, and in color from dark green to black. The dikes cut the country rock at many places and penetrate the joints in the granitic intrusives. They also cut the ore deposits in most of the mine workings. The diabase dikes are generally larger, more coarsely crystalline, and older than the basalt dikes, which are cut by the diabase dikes.

PETROGRAPHIC DETAIL.

Specimen 265. Hornblende dolerite. This rock, from the north shore of Karta Bay, contains about 45 per cent of labradorite in phenocrysts surrounded by a groundmass including both granular and poikilitic hornblende. The hornblende is of the typical basaltic variety, having a maximum extinction of 10° and pleochroic as follows: Z and Y dark red-brown, X very light yellow-brown, absorption Z>Y>X. This hornblende is rare in the basic igneous rocks of southeastern Alaska, its place usually being taken by varieties of common hornblende. The rock contains about 10 per cent of magnetite, which crystallized early, in branching and simple octahedral forms. The rock contains a small amount of biotite, which is pleochroic, ranging from almost black to very light yellowish brown.

Specimen 65. Dolerite (diabase), from a dike about 4 miles south of Hadley. A medium to fine grained rock containing zoned plagioclase of composition ranging from Ab_2An_3 to Ab_1An_3. Titaniferous augite occurs both in grains and in irregular masses having an ophitic intergrowth of feldspar. Magnetite inclosing feldspar forms large poikilitic masses.

Specimen 11. Hornblende basalt, from a dike 3½ miles northwest of Hadley. This rock is hypocrystalline porphyritic, having phenocrysts of hornblende, completely altered to serpentine and chlorite, scattered through a groundmass of plagioclase, augite, basaltic hornblende, iron ore, and glass. The augite is in part at least earlier than the feldspar, the basaltic hornblende is in part earlier and in part later than the feldspar. Interstices among the minerals once probably filled with glass are now masses of calcite and chlorite. Many small amygdules have been lined with chlorite and subsequently filled with calcite.

Specimen 386a. Melaphyre (basalt). A fine-grained hypocrystalline rock containing scattered phenocrysts of serpentinized augite and feldspar (Ab_2An_3). The partly glassy groundmass or base is filled with dark-brown needle-shaped crystallites, which extinguish obliquely. Amygdular cavities are filled with calcite.

AGE.

The geologic period in which these basic diabase and basaltic dike rocks were intruded into the metamorphic rocks of Kasaan Peninsula can be determined only by their relations to the other intrusive rocks. These dike rocks intersect the granitic intrusives, the porphyries, and the ore deposits, and also occur along joint planes both in the intrusive and intruded rocks. They are therefore the most recent rocks formed on Kasaan Peninsula and, judging from the occurrence of these rocks at other localities in the Ketchikan district, they are probably of Tertiary age. The basalt dikes crosscut the dikes of diabase and dolerite and are therefore the younger.

GEOLOGIC HISTORY.

The geologic record of events on Kasaan Peninsula begins with the deposition of a series of fragmental rocks, now represented by banded quartzites, graywackes, and conglomerates, and some tuffaceous beds. This series includes narrow beds of limestone which, though no fossils were found in them, are believed to be Devonian. The entire series is much folded and its beds stand nearly vertical, so that its thickness is difficult to determine, but it is believed to be several thousand feet thick.

There is no other geologic record until the early part of the Mesozoic era, but in the meantime these sediments were subjected to intense metamorphism and partial recrystallization due to pressure of overlying strata and to structural changes, which caused the beds to become intricately folded, the direction of the axes of folding being generally northwest.

During early Mesozoic time the rocks of the region were invaded by granitic intrusives. This granitic intrusion was a most important geologic event, as it caused the deposition of the ore bodies. It extended over a long period and produced much fracturing, folding, and metamorphism of the invaded rocks. This intrusion was probably deep seated and the intruded rock solidified far below the surface of that time, as there is no evidence that it extended to the surface. After the granite solidified the pegmatite-aplite dikes were injected from the still

fluid portions of the granitic magma. Cracks and fissures were then formed near the contact of the intrusive rocks. These openings, which may have been caused by contractions due to further cooling of the intrusive mass, served as channels for carrying the mineralizing solutions from which the ores were deposited.

The porphyritic dike rocks were also intruded into the sedimentary strata about this time and produced much metamorphism in the adjacent sediments, and locally along the contact rock sulphides were formed, though so far as known less abundantly than along the granitic masses.

A period of active erosion followed the uplift of the Kasaan Peninsula caused by the invading granitic masses, and during this epoch the main valleys, Clarence Straits and Kasaan Bay, which may have been begun at an earlier period, were greatly deepened. This period of erosion continued until the underlying granitic intrusives were exposed and the main features of the present topographic relief were formed. Later the land subsided, these main valleys became salt water channels, and then followed the ice period, which submerged these mountains under a sea of ice. The ice streams advanced from the northwest, carried erosion still farther, and brought with them bowlders and débris foreign to the region, depositing this material on the hilltops and forming bench deposits on the valley slopes. After the retreat of this ice sheet erosion continued to deepen the gulches and remove the deposits left by the glaciers.

The effects of this erosion on the ore deposits, located as they are on the mountain tops and hillsides in rocks little affected by chemical action, such as oxidation, has been extensive and therefore the ore deposits are primary, whereas those in most mineral-bearing regions are secondary.

COPPER ORES.

GENERAL FEATURES.

The copper deposits on Kasaan Peninsula consist of primary ores which show but slight traces of weathering or of concentration by circulating waters. They are similar in occurrence to the ores on Copper Mountain, which have already been described (p. 44).

Four types or ore deposits, defined principally by their mineral composition but also by their mode of occurrence, have been recognized:

1. Contact deposits forming irregular masses along intrusive contacts and consisting of chalcopyrite-magnetite ores and chalcopyrite-pyrrhotite ores associated with amphibole, garnet, feldspar, epidote, and calcite.

2. Disseminated deposits forming irregular, ill-defined masses in gabbro intrusives, and consisting of bornite-chalcopyrite ores intimately associated with the primary minerals of the intrusive rock and secondary epidote and calcite.

3. Shear-zone deposits occupying fissures along shearing planes in the graywackes, consisting of chalcopyrite-pyrite-sphalerite ores associated with a quartz-calcite-barite gangue.

4. Vein deposits occupying fissures in limestones and granitic intrusives and consisting of galena-sphalerite-chalcopyrite ores in a quartz-calcite-barite gangue and auriferous pyrite in quartz veins.

The deposits of the first and third types are the principal copper producers (1908). Deposits of the second type are being developed at several places, and from one mine—the Goodro—shipments of ore taken from deposits of this type have been made. Deposits of the third type have been developed at the Rush & Brown mine and at certain prospects. The vein deposits of the fourth type have been prospected at several points but have not yet been mined.

CONTACT DEPOSITS.

OCCURRENCE.

The term "contact deposit" is here restricted to mineral veins or ore masses that have been formed by contact-metamorphic action and that carry the minerals characteristic of such action. A contact deposit must therefore lie near an intrusive rock, though not necessarily at its contact.

At the time of their intrusion the igneous rock masses or dikes forced their way through the sedimentary rocks, to some extent folding and fracturing them. While they were cooling both the intruded and intrusive rocks naturally shrunk somewhat, and the shrinkage caused cracks and fissures to form near the contacts. These fissures became channels for mineral-bearing solutions, derived, presumably, from great depths, where the temperature was high. On ascending along the contacts, where the temperature was lower, these solutions deposited their mineral content and to some extent replaced the rocks along their course. The contact deposits therefore lie within the contact zone, between the intrusive and intruded rocks, and are believed to have been derived from the same magma that formed the adjacent igneous rocks. Their genesis, however, will be discussed elsewhere (p. 102).

CHARACTER.

The minerals commonly associated with the contact deposits are chalcopyrite, pyrrhotite, pyrite, and magnetite. The gangue minerals are principally garnet and pyroxene, with which are associated variable quantities of epidote, calcite, quartz, amphibole, wollastonite, and feldspar, besides several rarer minerals. These minerals are typical of contact-metamorphic deposits. Mineralogically, these ores differ from the ores of other deposits, especially in the contemporaneous formation of metallic oxides and sulphides, principally of iron, in association with the various lime-silicate minerals named above.

The ore deposits themselves within the contact zone consist of irregular masses ranging in diameter from a few feet to 100 feet or more. Few of them have well-defined limits, most of them merging gradually into barren contact rock. At a few places the ore-bearing contact rock is surrounded by the granitic intrusives; at other places it is surrounded by sedimentary rocks, no surface exposures of the intrusive rock appearing near it. Veins of contact rock carrying ore also cut the intrusive as well as the intruded rocks, though these veins are of little commercial importance.

The copper ore is entirely chalcopyrite and occurs in small masses and grains scattered through the contact rock, and also in the masses of magnetite. Only the parts of the contact rock or magnetite bodies that are sufficiently rich in copper to be profitably mined are regarded as ore.

EFFECT OF INCLOSING ROCK ON ORE FORMATION.

The size of the contact deposits and the width of contact rock at any particular place depend to some extent on the size of the intrusive mass at that place. The largest contact deposits on Kasaan Peninsula are those that have been exploited at the Mamie and Mount Andrew mines, which are near the large intrusive mass that constitutes the southeastern half of the peninsula. Smaller deposits, some of them, however, richer in copper, lie near smaller intrusive masses. These smaller deposits are exploited by the It and the Rush & Brown mines. Still smaller deposits lie near dikes of syenite porphyry and many of them have been prospected, though none have yet afforded ore bodies large enough to be mined profitably.

The general occurrence of the contact deposits at places where limestone is the intruded rock suggests that the lime carbonate helped to effect the precipitation or development of the ores at such points.

DISSEMINATED DEPOSITS.

Irregular disseminated bodies of copper ore occur in an intrusive belt of gabbro that extends along the northeast side of the salt chuck at the head of Kasaan Bay, extending northwestward and averaging about a mile in width. Copper ore has been found at only a few places in this intrusive belt and has been mined only at the Goodro mine.

Where the ore deposits occur the gabbro is partly recrystallized and contains large crystals of biotite and crystals of feldspar having a poikilitic mottling due to partial replacement by biotite. The rock also contains epidote and groups of large crystals of orthoclase, with biotite and epidote and some garnet. The bornite and chalcopyrite ores occur with the secondary minerals last named. It appears that these ore minerals were introduced into the gabbro by

the same mineralizing agencies that caused the metasomatic development of the secondary minerals. These agencies may have been directly related to those that produced the contact deposits; and if so, these deposits are only a phase of the contact deposits.

SHEAR-ZONE DEPOSITS.

Ore bodies representing shear-zone deposits occur near the head of Karta Bay, at the Rush & Brown mine and at the Venus prospect. These deposits consist of lenticular veins, from a few inches to a foot or more wide, of massive sulphide minerals, the veins being distributed along shear zones, from 2 to 10 feet wide, in the graywacke country rock.

The deposits contain chalcopyrite, pyrite, and some sphalerite in a gangue of much-altered graywacke and some quartz and calcite.

VEIN DEPOSITS.

Vein deposits that occupy fissures in limestone, from 1 foot to 5 feet wide, have been prospected on Kasaan Mountain. They contain galena, tetrahedrite, some sphalerite, and chalcopyrite, their principal valuable metallic content being lead and silver and some gold. The gangue minerals are quartz, calcite, and barite, but chiefly quartz.

Quartz veins carrying pyrite and some gold and chalcopyrite have been prospected on Grindall Point, at the south end of Kasaan Peninsula. The veins occur in the granite intrusives and measure 6 feet or more in width. These deposits have been exploited by prospect shafts and tunnels, but the ore is of low grade and no great amount of it has been found.

PERSISTENCE OF ORE BODIES.

These various types of ore bodies show different degrees of persistence. The contact deposits are generally small, irregular masses and are no more persistent in depth than they are laterally, but where these masses have been found in a wide contact zone further exploration will probably reveal similar ore masses, both laterally and in depth. The copper-iron sulphide deposits in shear zones in the stratified rocks are more persistent than the contact ore bodies and probably go deeper. The vein deposits in the limestones will also be extensive in depth, but will vary greatly in width, in places narrowing to a mere seam. To judge from like deposits elsewhere, possibly the lead-silver ores will be replaced by copper ores in depth.

MINERALS OF THE DEPOSITS.

The minerals in the ore deposits on Kasaan Peninsula are very similar to those that occur in the Copper Mountain region already described (p. 47). It is not necessary to repeat these descriptions here, but a list of the minerals found in the different types of ore deposits is given below.

Contact deposits.		Disseminated deposits.	Shear-zone deposits.	Vein deposits.
Chalcopyrite.	Garnet.	Chalcopyrite.	Chalcopyrite.	Galena.
Pyrite.	Epidote.	Bornite.	Pyrite.	Tetrahedrite.
Pyrrhotite.	Hornblende.	Chalcocite.	Sphalerite.	Chalcopyrite.
Magnetite.	Diopside.	Pyrite.	Galena.	Sphalerite.
Specularite.	Scapolite.	Native copper.	Quartz.	Pyrite.
Ilvaite.	Wollastonite.	Epidote.	Sericite.	Quartz.
Molybdenite.	Orthoclase.	Amphibole.	Calcite.	Calcite.
Azurite.	Chlorite.	Biotite.	Chlorite.	Siderite.
Limonite.	Quartz.	Calcite.	Amphibole.	Barite.
Malachite.	Calcite.	Quartz.		Chlorite.

In the contact deposits on Kasaan Peninsula the amount of hornblende and feldspar in the contact rock is greater than in the similar deposits on Copper Mountain, for the graywacke, which at most places forms the hanging wall of these deposits, has entered largely into their composition. Tremolite and wollastonite are rare, having been found only where limestone beds occur at the contacts. No zeolite was found. A few specimens of ilvaite with calcite matrix were noted in the contact deposits. (See Pl. XIX.)

Bornite and chalcocite, which occur in the disseminated deposits, were not found in the Copper Mountain area. The mode of occurrence of the minerals in the vein and shear-zone deposits is similar in both districts.

MINING ON KASAAN PENINSULA.

HISTORY.

Copper was first discovered on Kasaan Peninsula by the Russians about 1865. Between 1895 and 1900 most of the mineral locations were made and the mine developments were begun. During the following five years there were more extensive developments and nine plants were installed, aerial tramways were erected, and a smelting plant was built at Hadley. Copper was first produced from these mines in 1905, the year in which the Hadley smelter was completed. Copper production continued, gradually increasing in amount, until the autumn of 1907, when most of the mines ceased operations.

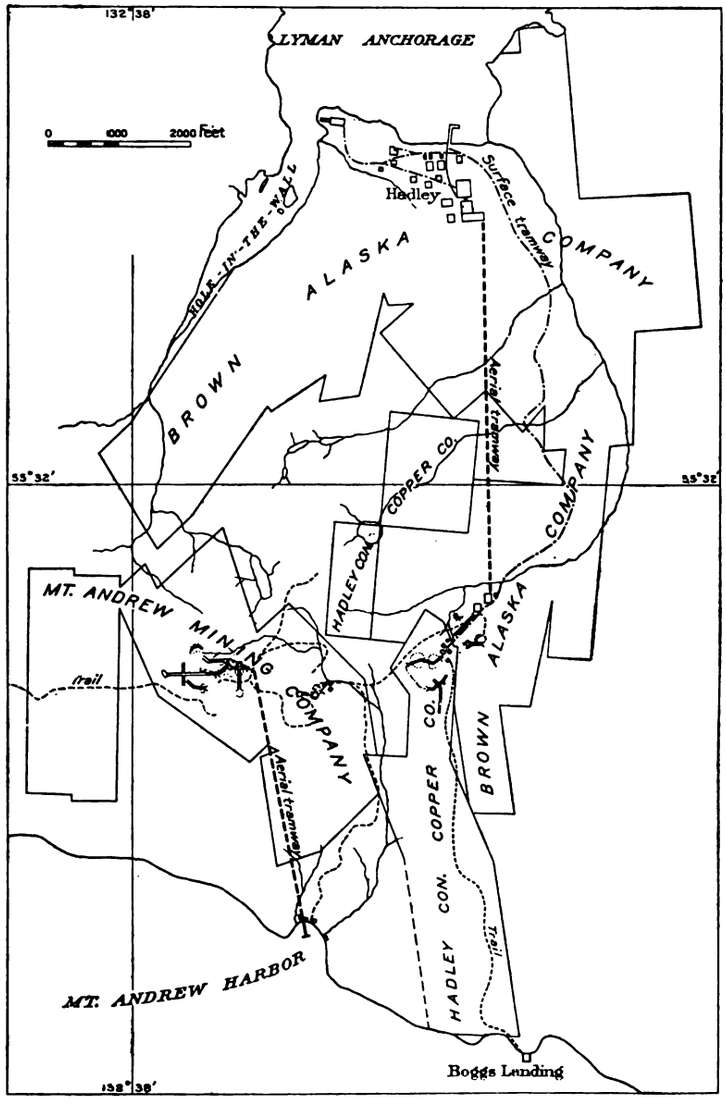


FIGURE 7.—Map showing properties of the Brown Alaska Co., Hadley Consolidated Copper Co., and Mount Andrew Mining Co. (1908).

In the summer of 1908 the Hadley smelter was again in use, and some of the mines renewed operations, but for a short period only. From 1909 to 1913 the smelter was idle, though certain of the mines continued operations, shipping the ore to the Tyee and Tacoma smelters.

MINES SOUTH OF HADLEY.

GENERAL FEATURES.

Three of the principal mines on Kasaan Peninsula are near the summit of the mountain ridge about 1½ miles south of Hadley, at altitudes of 700 to 1,400 feet. These are the Mamie, Stevenstown, and Mount Andrew mines, and their relative positions and the extent of the mining property belonging to the companies owning them in 1908 are indicated on the sketch map forming figure 7. The ore bodies are included in the contact rock and are associated with large masses of magnetite. They occur along a mineral zone between the diorite intrusive mass and a narrow belt of limestone, which is traceable for about 2 miles from the east side of Mamie Creek westward to Kasaan Bay. This zone ranges

in width from 100 to 300 feet, though, because of its flat dip and its conformity with the contour of the mountain slope, it appears locally to be much wider. The ore bodies are locally concentrations of chalcopyrite, generally in masses of magnetite. Though the ore masses discovered are limited both laterally and in depth, continued exploration has generally revealed new ore bodies both in depth and laterally.

The ores from these mines are of low grade, the copper content being almost entirely in the form of chalcopyrite. Besides copper they contain from $1 to $2 in gold per ton. In composition they average about 15 to 20 per cent of silica, 30 to 40 per cent of iron, 4 to 6 per per cent of sulphur, and 10 to 15 per cent of aluminum.

MAMIE MINE.

Situation and development.—The Mamie mine, owned by the Brown Alaska Co., is 1¼ miles south of Hadley, at an elevation of 700 feet, in the central part of Kasaan Peninsula. (See Pl. XX and fig. 7.) The mine workings are connected with the smelter at Hadley by an aerial tram 5,500 feet in length and with the beach by a horse tram 7,700 feet in length. The horse tram is used for transporting supplies. Mine developments in a large way were not begun until 1904. During that year the ore bodies were explored by numerous open cuts, tunnels, and diamond-drill holes. In the following year mining was begun from the open pits and new ore bodies were developed by tunnels and shafts. At the close of 1905 considerable ore was delivered to the smelter, and throughout 1906 the production was large. In 1907 diamond-drill investigations were advanced, new ore bodies were located at greater depth, and the ore

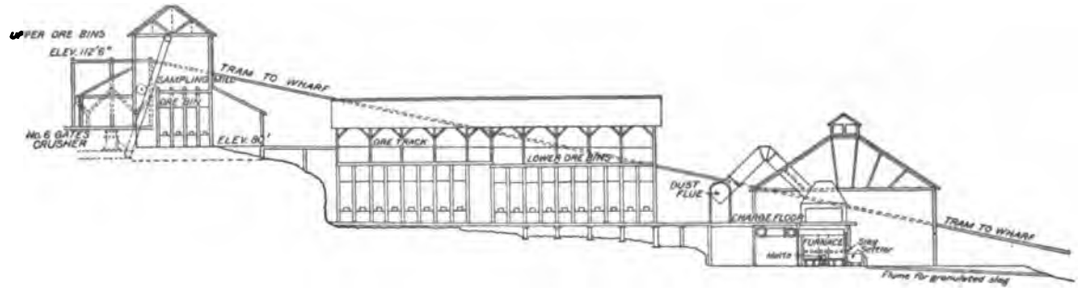


FIGURE 8.—Section of Hadley smelter.

production continued with little interruption until late in September. In October all operations were suspended. The total developments up to 1908 consist of 5,000 feet of tunneling, drifting, and crosscutting and about the same amount of diamond-drill prospecting. The smelter or reduction plant at Hadley consists of a blast furnace of 350 tons daily capacity, a sampling mill, coal and coke bins, ore bunkers of 10,000 tons capacity, boiler house, engine house, electric-light plant, and other conveniences. The ores from the Mamie and Stevenstown mines first go through the samplers, next to the ore bunkers by gravity, and thence by gravity to the furnace. The slag from the furnace is granulated and carried by water to the beach. A cable tramway extends from the wharf to bins above the sampling mill, which have been built to receive custom ore. The plant is so arranged that its daily capacity may be doubled if necessary. Smelting operations began December 5, 1905, and in 1906 the furnace was in blast about 20 days each month. In September, 1907, this plant was closed. (See Pl. XXI, *B*, and fig. 8.)

Early in the summer of 1908 the Mamie and Stevenstown mines were consolidated under one management, which obtained a lease of the smelter. The underground workings at the Mamie mine were pumped out and repaired and mining developments were begun. The smelter was reconstructed to treat a larger quantity of ore and was put into operation early in September. The mines and smelter were operated until the first of November, the smelter treating an average of 360 tons daily. The lack of siliceous ores, however, necessitated the suspension of operations at both the mine and smelter. The Mamie mine and Hadley smelter have both been idle since 1908 (1913).

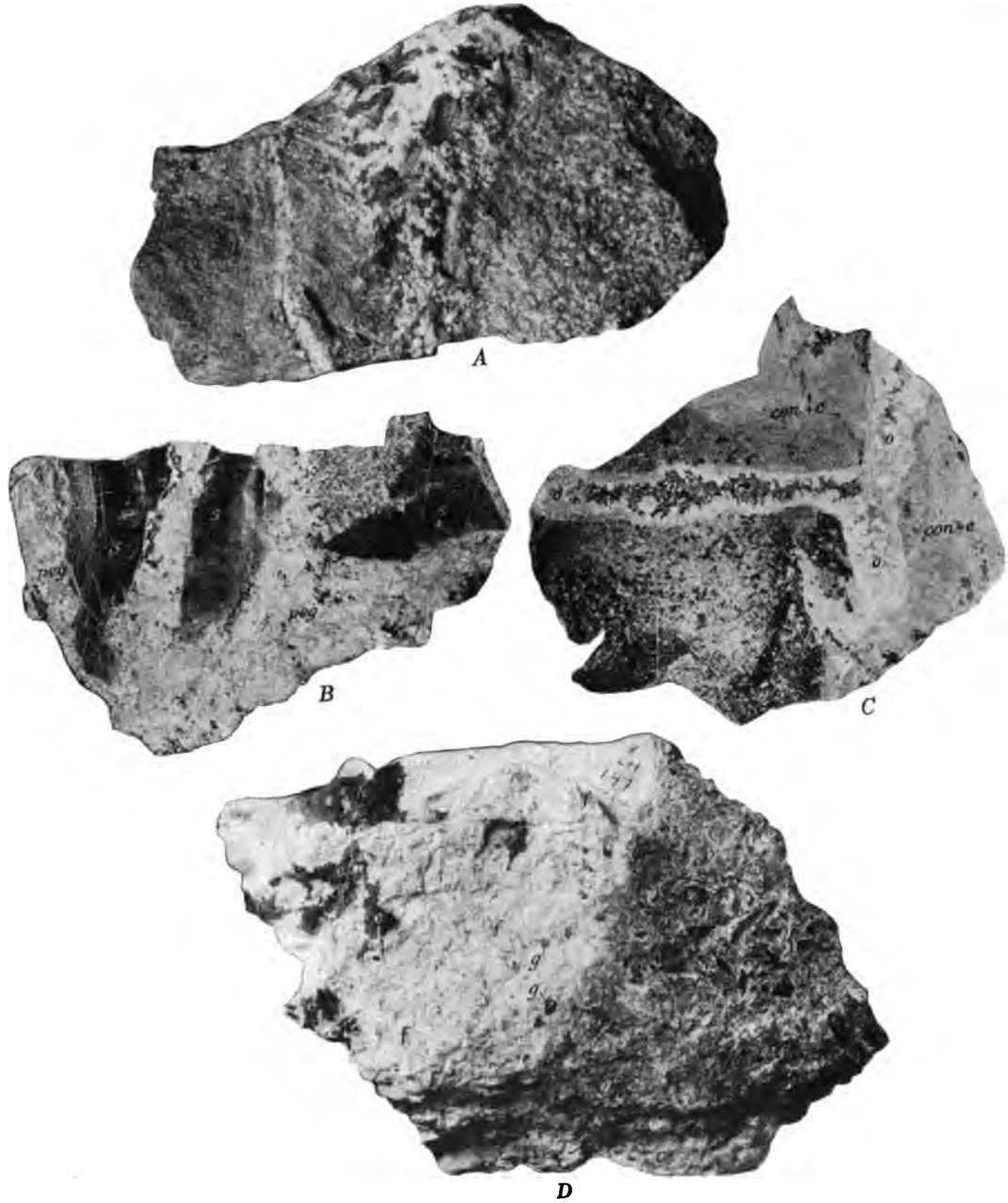
PLATE XVIII.

A. Specimen from Rush & Brown mine, showing contact of diorite with graywacke and development of pegmatite along contact.

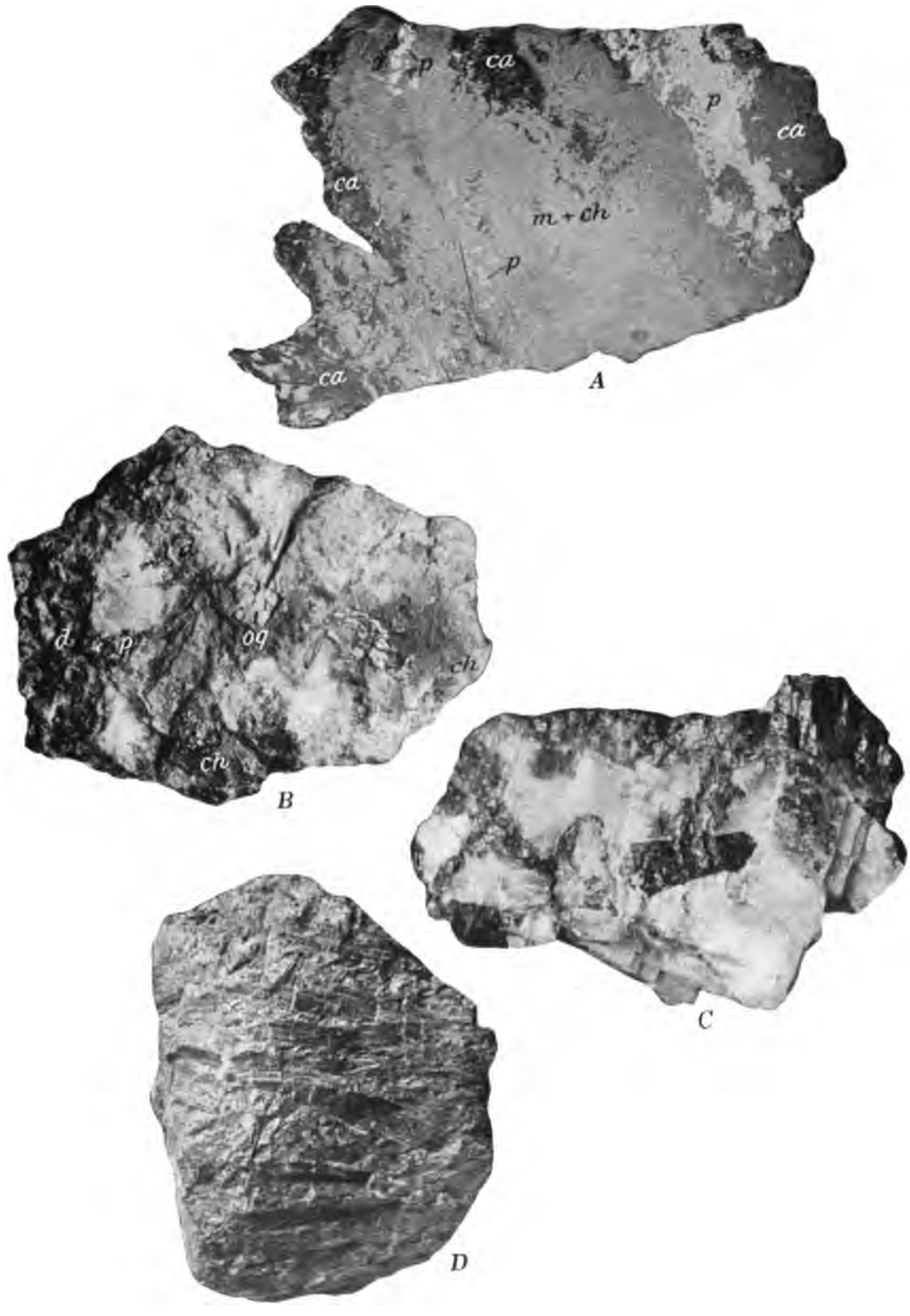
B. Pegmatite phase of diorite, with inclusions of schist; *peg*, pegmatite; *s*, schist.

C. Specimen from Mount Andrew mine, showing orthoclase veinlet cutting altered diorite and entering contact rock; *con*, Contact; *e*, epidote; *d*, altered diorite; *g*, garnet; *o*, orthoclase veinlet.

D. Feldspar dike with epidote cutting contact rock; *c*, calcite; *e*, epidote; *f*, feldspar; *g*, garnet; *h*, fibrous hornblende.



ROCKS FROM MINES ON KASAAN PENINSULA.



ORES AND MINERALS FROM MINES ON KASAAN PENINSULA.

PLATE XIX.

A. Ore from Mount Andrew mine, showing association of magnetite, pyrite, and chalcopyrite in contact rock; *ca*, calcite amphibole rock; *m* + *ch*, magnetite and chalcopyrite; *p*, pyrite.

B. Ore from It mine, showing altered diorite, chalcopyrite, and pyrite in orthoclase quartz contact rock· *d*, diorite; *ch*, chalcopyrite; *p*, pyrite; *oq*, orthoclase and quartz.

C. Ilvaite from Mount Andrew mine.

D. Hornblende with chalcopyrite ore from Stevenstown mine.

Ore bodies.—The ore bodies at the Mamie mine are contact deposits included in a zone 400 feet wide lying between a diorite intrusive mass and a limestone. Within this zone the masses of valuable copper ore are limited either by such a decrease in the copper content of the inclosing rock as to prohibit profitable extraction or by fault planes. Garnet, pyroxene, epidote, hornblende, and magnetite compose the contact rock. Chalcopyrite occurs in small quantities throughout the rock. The ore bodies, or the portions of the contact rock where the copper is sufficiently concentrated to make ore, are irregular masses ranging from 50 to 100 feet in length and from 10 to 40 feet in width, the major axis striking northward. Nine such ore masses are exposed in the mine workings. Some of them are included entirely in masses of magnetite, thus making basic ore; others occur in the garnet-epidote gangue rock, making a siliceous ore. Veinlets of calcite and some of quartz intersect the ore masses, indicating a later period of mineral deposition, though the main ore bodies are believed to have been deposited contemporaneously with the inclosing contact rock. (See Pl. XVIII, *B* and *D*.)

STEVENSTOWN MINE.

Situation and development.—The Stevenstown mine (Pl. XXI, *C*), owned by the Hadley Consolidated Copper Co., is just above and southwest of the Mamie mine, at an elevation of 1,000 feet. (See fig. 7.) From the mine a surface tram 700 feet long connects with the aerial tram at the Mamie mine, over which the ore is transported to the smelter at Hadley. A trail also leads from the mine down the south side of the peninsula to Boggs Landing, on Kasaan Bay, a distance of 1 mile. In 1908 the mine was developed by three "glory holes" or open pits, connected by raises with a 550-foot tunnel that penetrates the crest of the mountain. Actual mining was begun in June, 1905, before which time prospecting had been carried on, and in September, 1905, ore shipments to the Hadley smelter began. A large amount of ore was produced during 1906 and until the first of July, 1907, when mining was suspended. In 1908 operations were renewed and additional output was made and sent to the smelter at Hadley. In the autumn of that year, however, the mine was closed.

Ore bodies.—The ore bodies on the Stevenstown property correspond both mineralogically and genetically with those at the Mamie mine. They occupy a relatively flat position on the crest of the mountain ridge and are apparently underlain by the monzonite intrusive which forms the footwall of the mineral belt and which is exposed throughout the tunnel that penetrates the mountain top. The hanging wall as well as a large portion of the ore bodies on this property have been removed by erosion and the contact zone is only 20 to 40 feet in width instead of 200 to 400 feet, the width on the Mamie property just below. Strata of limestone and of greenstone tuff lie northeast of the ore bodies and continue westward toward the Mount Andrew mine, forming the hanging wall of the mineral zone.

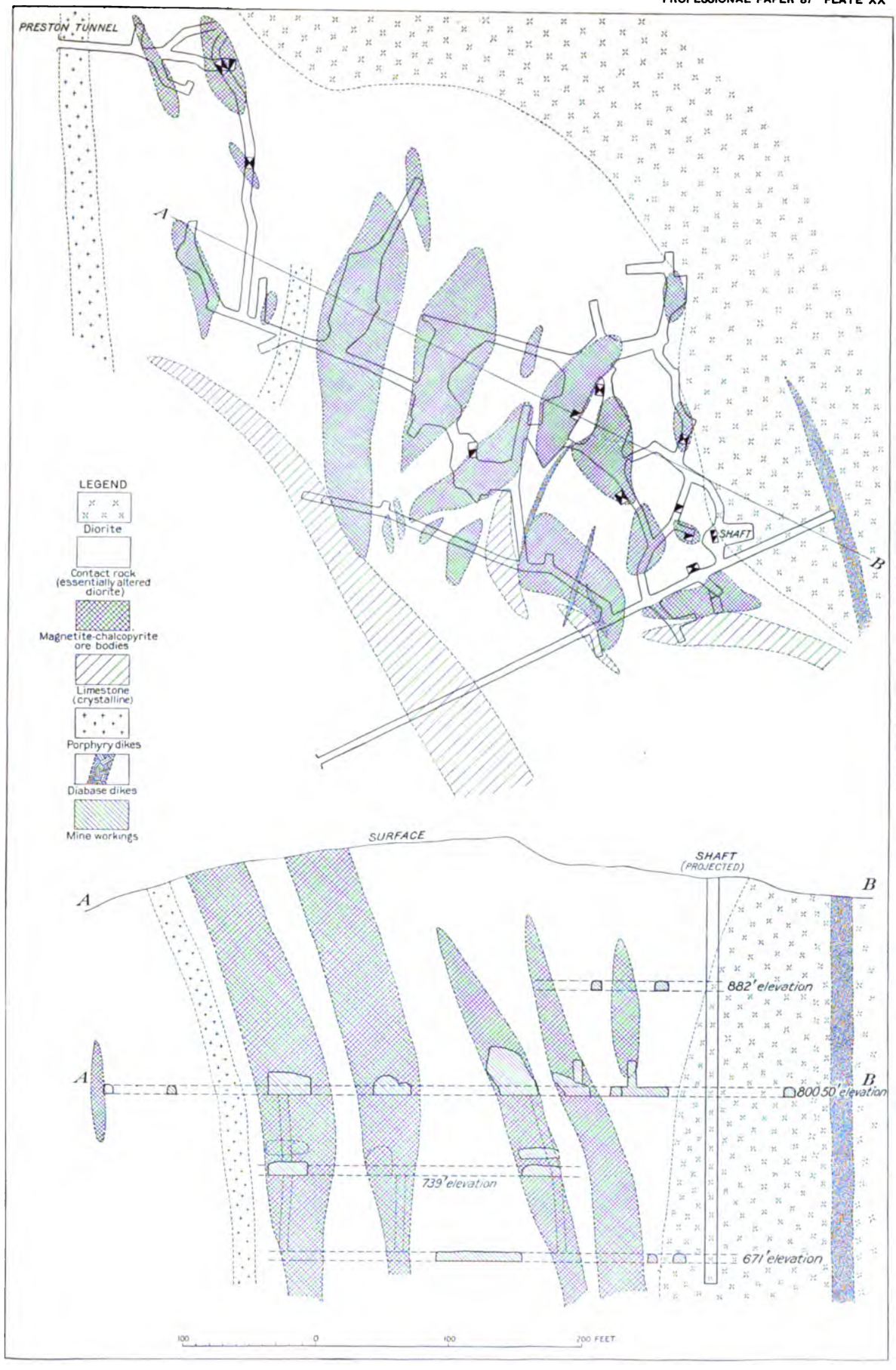
The mine workings are all surface pits connected by raises with the main tunnel and have developed several relatively flat-lying ore masses. These masses are included within an area measuring 350 by 200 feet, the pits being 20 to 40 feet deep. The central portion of this area is traversed from north to south by a 40-foot felsite dike, which is of later intrusion than the syenite and crosscuts the ore body. Smaller dikes of diabase and basalt, 1 foot to 5 feet in width, crosscut the ore bodies and country rock at several points in these mine workings.

The ore is chiefly magnetite, chalcopyrite, and pyrite associated with hornblende and calcite, all included in a more or less banded garnet-epidote gangue. (See Pl. XIX, *D*.)

Surface oxidation has produced considerable limonite and some malachite and azurite; small particles of native copper also occur along slipping planes, though these secondary minerals are relatively unimportant.

MOUNT ANDREW MINE.

Situation and development.—The Mount Andrew mine workings are three-fourths of a mile from Mount Andrew landing, on the southwest side of Kasaan Peninsula, and one-half mile west of the Stevenstown mine, at an elevation of 1,400 feet. A cable tramway 3,600 feet long leads from the mine to the ore bunkers and wharf at Mount Andrew landing.



PLAN AND SECTION OF WORKINGS OF MAMIE MINE IN 1908.

A. SURFACE WORKINGS OF MAMIE MINE IN 1908, SHOWING TRAMWAY TO STEVENSTOWN MINE.

B. HADLEY SMELTER.

C. WORKINGS OF STEVENSTOWN MINE IN 1908.

This mine is developed (1908) principally by a tunnel 620 feet long, which undercuts the ore bodies at depths of 60 to 100 feet or more. From this tunnel several hundred feet of drifts and crosscuts have been driven, and upraises have been carried through the ore bodies to the surface. The ore is mined from large underground stopes and from surface pits or glory holes and is delivered through chutes at tunnel level to the ore bunkers at the head of the aerial tram and thence carried to the wharf, where it is loaded for shipment. Developments in a large way were not begun until late in 1905, and during 1906 the aerial tram was erected, the wharf built, the compressor plant installed, and considerable ore developed. The first ore

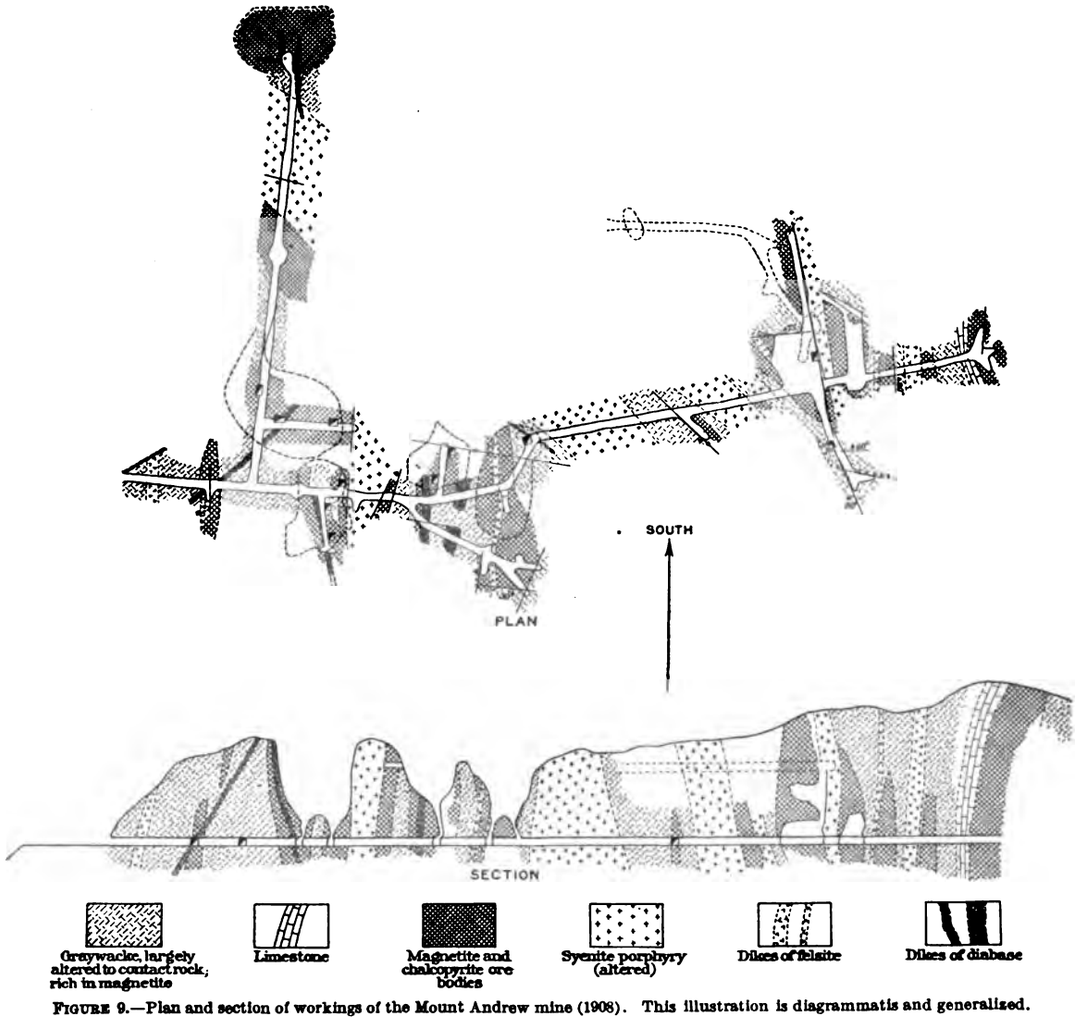


FIGURE 9.—Plan and section of workings of the Mount Andrew mine (1908). This illustration is diagrammatis and generalized.

shipments were made in October, 1906, and production continued until October, 1907, when operations were suspended.

In 1908 the mine was not operated. In 1909 operations were renewed under the management of the proprietary corporation, the Mount Andrew Iron & Copper Co., and from March until late in the autumn a steady output was maintained. During the winter of 1909 developments were continued and additional ore reserves were opened. Shipments began again early in the spring of 1910 and the usual annual production was recorded for that year. The most noteworthy development work undertaken in 1910 was that on the new 1,600-foot adit tunnel, which

starts at the old camp and is projected to undercut the ore bodies 300 feet below the present working levels. (See fig. 9.) In 1911 the mine continued producing, though its output was somewhat less than in former years.

Ore bodies.—The ore deposits on this property are included in the same mineral belt as those at the adjacent Mamie and Stevenstown mines, with which they are in every way comparable. Six ore bodies, consisting of irregular masses of magnetite-chalcopyrite associated with the garnet-epidote contact rock, have been developed and have been mined to a considerable extent. These bodies of ore are 10 to 50 feet wide, 40 to 80 feet long, 100 feet or more in depth, and have a general northerly strike and pitch. They are separated by barren areas of contact rock and dikes 20 to 60 feet wide of altered syenite porphyry. (See Pl. XXII, *A*, and fig. 9.) The mine workings consist essentially of surface pits which are undercut by a crosscut tunnel running east and west. This tunnel, with connecting drifts and raises, includes 2,200 feet of underground developments. Numerous gouge seams and slickensides, indicating faulting, were observed in the mine workings, and some of the ore bodies were laterally displaced 1 foot to 6 feet. Dikes of diabase and felsite, from 2 to 12 feet wide, crosscut the ore bodies and country rock in various directions and were evidently intruded after the ore deposits had been formed. (See Pls. XVIII, *C*, and XIX, *A* and *C*.)

At other points on Mount Andrew large masses of the magnetite carrying an amount of copper insufficient to make a copper ore have been formed. These deposits, though not valuable for their content of copper alone, may sometime be a source of iron.

MINES AND PROSPECTS NEAR KASAAN BAY.

TYPES OF DEPOSITS

Along the northeast shore of Kasaan Bay there are a number of copper prospects and one producing mine. Two types of contact deposits were recognized. One type, at the contacts of diorite masses, is represented by the It mine and the Alarm, Haida, and Copper Center prospects; the other type occurs at the contacts of dikes of syenite porphyry and diorite, and is represented by the Uncle Sam, Ouray, and Copper Queen prospects. The deposits of the first type are concentrations of chalcopyrite ore in the contact rock between the diorite and either the limestone or the graywacke. The bodies of minable ore are from a few feet to 25 feet or more in thickness and are generally more siliceous and richer in copper than those at the Mamie and Mount Andrew mines. The ore bodies along the syenite porphyry dikes contain rich ore here and there, but have added little to the copper production of the peninsula.

IT MINE.

Situation and development.—The It Mining Co. was organized early in 1908 and acquired what were formerly known as the Taylor prospect and the Eagle's Nest group. These prospects are 4 miles northwest of Kasaan, 4,000 feet from the shore line, at an elevation of 400 feet. They were developed to some extent in 1907 by the Sea Island Copper Mining Co., but reverted to the original owners, who sold them to the It Mining Co. Development work was begun by this company in May, 1908, and by the end of September a surface tramway 1 mile long and a wharf were completed, and in October of that year ore shipments were begun. In 1909 the mine was a steady producer and development work was advanced. A compressor plant was established near the wharf and a hoisting engine was installed at the mine. From the short adit level a shaft 50 feet deep was sunk and about 250 feet of development was done at this new level. In 1910 two other levels at depths of 100 and 150 feet were driven, and the ore production was maintained as in former years. Some prospecting was done by diamond drilling. In 1911 a 1,400-foot tunnel was begun, which is projected to undercut the ore deposits at a depth of 500 feet.

The ore from this mine is siliceous and contains little or no magnetite. The gangue is sorted by hand, the product being thus made richer before shipment. (See Pl. XIX, *B*.)

Ore bodies.—The ore bodies are contact deposits which lie on both sides of a diorite intrusive mass. (See Pl. XIX.) The contact zone here is widest on the northeast side of the diorite, where the principal ore bodies are found, though developments on the southwest side have also revealed small masses of ore. The intruded rocks are limestone and graywacke and have been much altered by infiltration of minerals from the contact zone.

The minable ore bodies consist of chalcopyrite, pyrite (often in large octahedral crystals), garnet, epidote, and some hematite. They are from a few feet to many feet in dimensions. Several such bodies have been found and mined and exploration, both in depth as well as laterally, continues to expose masses of ore.

UNCLE SAM MINE.

Situation and development.—The Uncle Sam mine, originally called the White Eagle group, lies 3 miles northwest of Mount Andrew landing and one-half mile from Kasaan, on the south slope of Kasaan Peninsula. (See fig. 10, p. 96.) The mine workings are 430 to 550 feet in elevation and less than half a mile from the beach. Mining operations have been advanced on this property at intervals since its discovery in 1899, and in 1901 an aerial tram, ore bunkers, and a wharf were built. Early in 1906 a shipment of ore was made, but no further work was done until March, 1907. At that time operations were renewed, continuing until July, when another ore shipment was made. The mine is developed (1908) by a tunnel and drifts, amounting to about 800 feet in length, and by open pits exposing the ore body on the surface above the tunnel. From this working tunnel a surface tram 1,150 feet long conveys the ore to the wharf. This mine has now (1912) been closed since the autumn of 1907.

Ore body.—The ore body exposed in the tunnel is an irregular lens of chalcopyrite-pyrite ore 6 to 8 feet in width, striking north and pitching about 45° N. It is cut off to the north by an east-west fault dipping 80° N., which shows but a small amount of gouge. At the open cut above the tunnel similar masses of ore are exposed, but no large ore bodies have been discovered. Garnet, epidote, magnetite, and calcite occur as gangue minerals and in many places form small geodes. The chalcopyrite ore contained in this gangue rock is irregularly distributed in small masses and not along well-defined lines. The country rock is made up of strata of chloritized and epidotized greenstone tuff, which are underlain by the intrusive syenite and are cut cross by small dikes of diabase of later origin than the ore bodies.

COPPER QUEEN GROUP.

The Copper Queen group of claims, which represents the first copper locations on Prince of Wales Island, lies about one-half mile southeast of Kasaan. In 1898 these claims were sold to the Kasaan Bay Mining Co., which made additional locations. Small operations were in progress from 1899 until 1902, and 500 feet of tunneling was done, besides surface excavations. Since 1903 the property has been idle.

The principal ore deposit is exposed along the side of a gulch at a point 300 feet in elevation. It consists of an irregular mass of chalcopyrite ore accompanied by pyrite and magnetite in a garnet-epidote gangue, at the contact of an altered intrusive syenite with the greenstone tuff. Below these exposures a crosscut tunnel 400 feet in length has been driven in the altered syenite, but has failed to reveal any ore.

Other mineral exposures occur on these claims at points close to tidewater and have been prospected by shafts and open cuts, but so far no important deposits have been discovered. Practically no work has been done on this property for several years (1912).

POOR MAN'S GROUP.

The Poor Man's group of two claims is 2 miles northwest of Kasaan. In 1908 the mine workings were connected with deep water by a surface tramway and wharf having a total length of about 2,000 feet. The principal developments are at the head of the tramway and consist of a tunnel, driven 90 feet in a southwesterly direction, which crosscuts a 40-foot body of magnetite

ore and 30 feet of garnet-epidote contact rock, and at its face enters a wide dike of red syenite for 20 feet. At a point 80 feet from the mouth of the tunnel is a vertical shaft extending 30

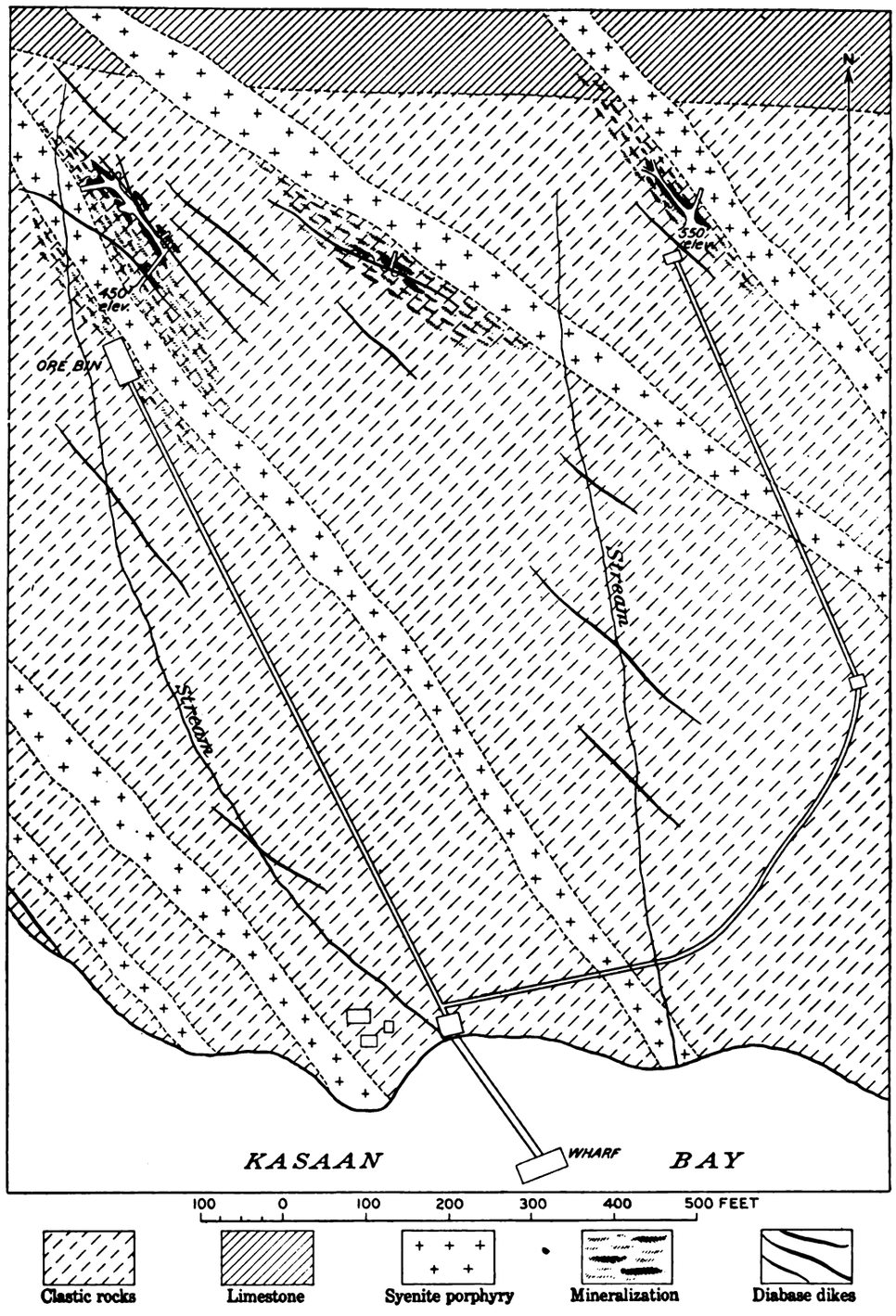


FIGURE 10.—Plan of workings of the Uncle Sam mine (1908).

feet to the surface and 60 feet in depth. This body of magnetite is exposed on the surface above the tunnel, and similar masses have been prospected by short tunnels and cuts and

shafts at points along the tramway and on adjoining properties. Associated with the magnetite are large amounts of calcite and hornblende and some pyrite, chalcopyrite, garnet, and epidote. Although the magnetite deposit itself is extensive, the chalcopyrite ore occurs only in isolated pockets or narrow veinlets and is not disseminated throughout the magnetite in sufficient amounts to make a copper ore of the entire body. It is noteworthy, however, that these ore bodies may be of value for their iron content. Minor displacements, due to faulting on slipping planes, and dikes of diabase and felsite crosscutting the deposits were noted.

BROWN & METZDORF PROSPECT.

The Brown & Metzdorf prospect is one-half mile from Kasaan Bay, at an elevation of 310 feet. The ore body is a mineralized mass of garnet rock carrying chalcopyrite and pyrite. It is exposed for a width of 10 feet, showing a banded structure, and evidently replaced the bedded quartzite and greenstone tuff country rock. A wide belt of limestone is exposed in bluffs along the trail just below this prospect.

PEACOCK AND TACOMA CLAIMS.

The Peacock and Tacoma claims are about 3 miles southeast of Kasaan. The Tacoma claim extends to the beach, where open cuts have been made on ore exposures that are covered at high tide. The ore is confined to a garnet-epidote rock and occurs in irregular patches or finely disseminated particles. In the cuts on the beach a small amount of ore is exposed, and above it, at an elevation of 50 feet, a tunnel 60 feet long (1908) enters the hill in a northeast direction. This tunnel crosscuts a wide belt of garnet-epidote rock containing some chalcopyrite. Other open cuts expose small amounts of ore at several places, but no large ore masses have been developed.

The Peacock claims adjoin the Tacoma claim on the north and extend to the center of the peninsula. At 600 feet from the beach and 120 feet above tide a tunnel 45 feet long exposes a belt of garnet-epidote contact rock containing magnetite and a small amount of chalcopyrite. Still higher, at 325 feet, a second tunnel 30 feet long, following the contact of a diabase dike, exposes a smilar mineral-bearing rock. Here also dikes of felsite and basalt occur, and slipping planes displace the mineral body in various directions. The amount of development on these properties has not been sufficient to disclose ore bodies large enough to justify mining, but systematic prospecting may open up deposits of value.

HOLE IN THE WALL PROSPECTS.

The small cove known as Hole in the Wall lies on the north side of the harbor at Hadley, and along its shores and west of it a number of claims have been located, among them (in 1908) the Plumley group and the Eureka, Sunrise, Pennsylvania, Venus, and Pelaska claims. On the Hilma claim of the Plumley group, at a point one-half mile northwest of the head of the cove and 310 feet in elevation, a tunnel 25 feet in length has been driven along the contact of an altered limestone belt with a dioritic batholith, in which small masses of chalcopyrite are exposed in a garnet-epidote-calcite contact rock. On the Eureka claim, at tidewater, similar contact deposits are being developed and are reported to be of considerable extent. The Sunrise claims, three in all, are west of the Hole in the Wall, and on these claims at points along a gulch small ore masses replace limestone beds at or near their contact with granodiorite. At an elevation of 1,050 feet this contact aureole is 25 feet wide and contains considerable magnetite and chalcopyrite ore, which shows much surface alteration. On the south slope of the hill, at an elevation of 950 feet, is an open cut exposing a highly crystalline marble, slightly banded, striking N. 65° E. and dipping 60° NW. This marble overlies the contact rock, which carries small amounts of the copper ore. On the Pennsylvania claims, southeast of the Sunrise claims, an open cut following a felsite dike at an elevation of 850 feet exposes a small vein 2 to 3 feet wide consisting of pyrite with small amounts of chalcopyrite. The prospects on the Venus claims show contact deposits similar to those exposed on the Sunrise claims to the north

and are apparently along the same intrusive contact. The Pelaska claim, extending from the head of the cove westward, has been developed by a tunnel over 100 feet in length following a belt of altered limestone intruded by a diabase dike, along which occurs garnet-epidote contact rock carrying some chalcopyrite. This deposit is interesting geologically, but the amount of ore exposed is small.

MINES AND PROSPECTS AT THE HEAD OF KASAAN BAY.

LOCATION.

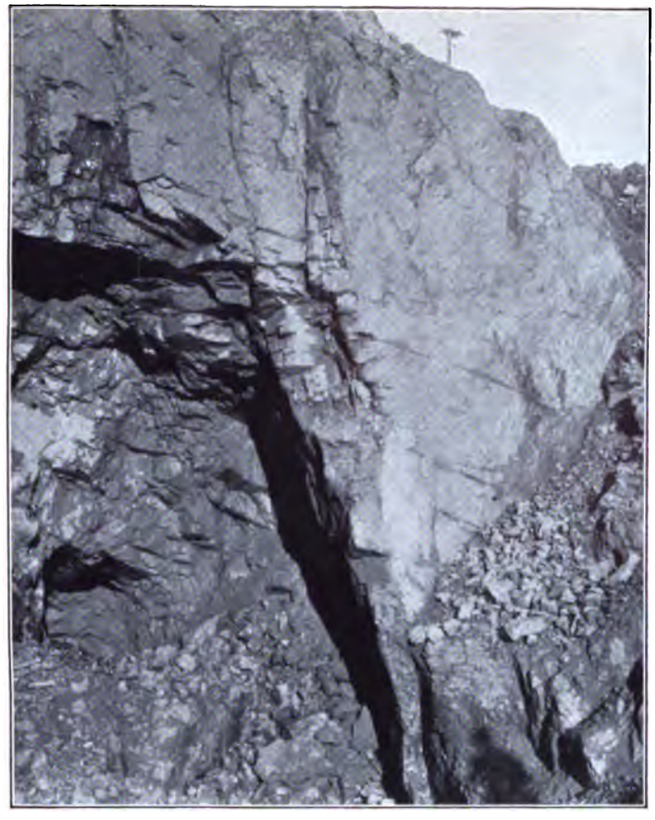
The head of Kasaan Bay includes the entire northwest extension of Kasaan Bay. It is a relatively shallow embayment 3 miles in width, including a number of low wooded islands and shoals, and affording several good anchorages. The adjacent land area is low and is occupied by a "salt chuck" 2 miles in length and by three small lakes. To the southwest is a mountain range including Granite Mountain and other rounded summits less than 4,000 feet in elevation, and to the northeast is a low ridge of hills forming the divide between Kasaan and Thorne bays. The principal mines in the immediate vicinity are the Rush & Brown mine and the Venus group to the northwest and the Goodro claims to the northeast. In 1901, when A. H. Brooks visited this section, none of these properties had been located, and not until 1904 were the copper-bearing ore bodies discovered.

The area is occupied principally by stratified rocks ranging from a fine tuff to a coarse conglomerate, and in places showing a development of large hornblende crystals. These bedded rocks are invaded by granodiorite masses, and dike rocks of various composition intrude both the granodiorite and the bedded rocks. The copper ore occurs (1) at the contacts of the granodiorite with greenstone tuff, conglomerate, and limestone, as at the Rush & Brown mine; (2) along shear zones in the greenstone tuffs and conglomerates, as at the Venus group and Rush & Brown mine; and (3) in small masses and disseminated particles scattered irregularly through an altered basic diorite, as at the Goodro claims.

RUSH & BROWN MINE.

Situation and development.—The Rush & Brown property includes (1908) eight claims extending from the "salt chuck" northwestward, the principal mine workings being located on the Iron Cliff claim, at an elevation of 300 feet, about 2 miles from the wharf at the head of the bay. (See fig. 11.) In 1904 this property was prospected by long trenches and open cuts, and a shaft 25 feet deep was sunk on the ore body. In 1905 it was leased by the Alaska Copper Co. and a new shaft was started 120 feet south of the old shaft and sunk to a depth of 84 feet. From the bottom of this shaft the principal ore body, the magnetite deposit, was developed by drifts and crosscuts and a drift was extended to a second ore body, the sulphide deposit, 160 feet farther northeast. In 1907 the shaft was sunk an additional 93 feet and another level was started. The ore from the mines is transported by a gravity tram to ore bunkers one-fourth mile below the mine and thence by a railroad 2¾ miles long to the wharf at the head of the bay, where ore bunkers of 2,000 tons capacity have been built. During 1906 ore was shipped to the smelter at Coppermount, and in 1907 shipments were made to the Tyee smelter at Ladysmith, British Columbia. The mine was practically idle during 1909–10. In 1911 work was again renewed and since then shipments of ore have been continued.

Ore bodies.—In 1908 two ore bodies had been developed at the Rush & Brown mine. One is a contact-metamorphic deposit consisting of a copper-bearing magnetite body, developed to a length of 100 feet and a width of 30 feet, in the contact-rock gangue lying between diorite and an altered graywacke, the line of contact striking nearly east and west. The other deposit, 160 feet to the north, occupies a shear zone in the greenstone tuff and conglomerate beds and is a sulphide body composed of chalcopyrite and pyrite in a gangue of altered graywacke and quartz and calcite. It is developed to a width of 4 to 14 feet and in 1908 had been followed for a length of 85 feet. The mine management in 1913 reported that the sulphide ore body on the second level was cut off by a fault but was picked up again and explored for a distance



A. PORPHYRY DIKE CUTTING ORE BODY NO. 4, MOUNT ANDREW MINE.

B. ENTRANCE TO SLOPE AND SURFACE CAPPING OF ORE BODY AT RUSH & BROWN MINE.

Photograph taken in 1908.

of 170 feet beyond the fault. The strike of this sulphide deposit is northeastward and its dip is 60° SE., toward the larger deposit. Further exploration will doubtless disclose other ore bodies of the same types. (See Pls. XVIII, *A*, and XXII, *B*.)

GOODRO MINE.

The Goodro mine, also known as the Joker group, is half a mile from the head of the salt chuck entering Karta Bay. The surrounding area is relatively low, the claim being located on a knoll about 400 feet in elevation. The copper deposit at this mine consists of disseminated sulphide ores in a gabbro intrusive belt, which is shown on the geologic map (Pl. XV). At the time of the writer's visit this deposit had been developed by surface pits, an open cut 70 feet long, and a tunnel 125 feet long, which crosscuts the deposit 90 feet below the surface and 90 feet from its mouth. In 1909 a wharf, ore bins, and 3,850 feet of tram (in part gravity and in part horse tram) were constructed, and the shipment of ore was begun. The ore was lightered out of the salt chuck on barges at high tide and loaded on vessels lying at the head of Kasaan Bay. In 1910, after the winter shutdown, operations were again resumed. A winze 100 feet deep was sunk from the main tunnel level, and from its bottom drifts were extended to the east and west 150 feet in length. The winze is said to have been sunk in ore for 45 feet. At the lowest level 14 feet of ore, consisting of disseminated chalcopyrite and bornite in the gabbro, is said to have been crosscut. In 1911 only assessment work is reported to have been done on this property.

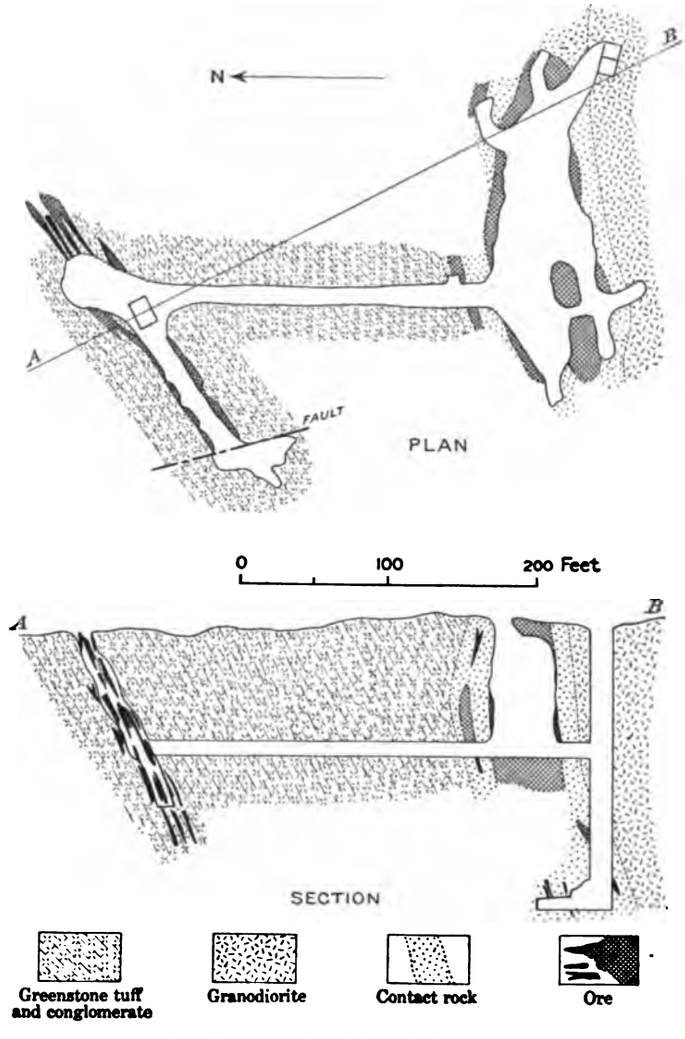


FIGURE 11.—Plan and section of the Rush & Brown mine (1908).

The ore deposit at this mine is of special interest because bornite is the dominant metalliferous mineral, and it is the only locality in southeastern Alaska where bornite has been found in quantity. The ore occurs in small masses and disseminated particles associated with epidote, feldspar, and biotite, minerals that largely replace the inclosing gabbro. Native copper, chalcocite, chalcopyrite, and small amounts of gold are also associated with the bornite. The mineralization of the gabbro with bornite is exposed across a width of 60 feet and for a length of 100 feet or more. Other smaller deposits of bornite in the gabbro were noted on adjacent properties.

MAMMOTH GROUP.

The Mammoth group, including the Haida mine, lies on the east side of Kasaan Bay, about 6 miles from Kasaan and one-third of a mile from tidewater on the top of a low hill 500 feet in elevation. The property was largely developed in 1904–5 by the original owners, and in June, 1906, was sold to the Haida Copper Co., which began active developments and made plans for erecting a gravity tram 2,000 feet in length, extending to the beach, and a wharf and ore bunkers. In April, 1907, these improvements were completed and the company made shipments of ore to the Hadley smelter. Early in the summer, however, operations were suspended, and the mine has since been idle. The mine is developed by a tunnel 120 feet in length, connecting with a shaft 35 feet deep, which in turn connects with a surface pit on the ore body. In 1908 exploratory drifts had been extended from the tunnel, and prospect pits and short tunnels have been driven at other points on the property. Little work has been done at this prospect in recent years.

The ore body is an irregular magnetite mass carrying chalcopyrite in a gangue of garnet and epidote. The country rock in the immediate vicinity is made up of greenstone tuff and conglomerates, though just below the mine workings a belt of intrusive diorite is exposed which forms the western half of the ridge and probably underlies the ore body. The deposit is developed by an open pit over an area about 50 feet in diameter. This is undercut by a tunnel at a depth of 30 feet, and though the magnetite is exposed at this depth, chalcopyrite is not so abundant. To the northeast the ore body is limited by a fault plane striking nearly east and west and dipping 75° S. Other slipping planes striking at different angles were noted in the ore body and inclosing rock.

COPPER CENTER PROSPECT.

The Copper Center group of claims lies 1 mile north of the Mammoth group at an elevation of 400 feet. It was located in April, 1907, and in July was bonded to mining men who undertook its development. In 1908 several shafts from 10 to 30 feet deep had been sunk within an area 300 by 120 feet. In all these shafts and surface cuts magnetite and chalcopyrite ore associated with garnet-epidote and hornblende gangue is exposed. The deposit is apparently flat lying, though the amount of work done is hardly sufficient to prove that it does not continue in depth. It is also probable that further investigations at a greater depth will reveal deposits at other points on the property. The country rock is largely conglomerate and greenstone tuff, underlain by granodiorite, which is exposed down the hillside to the southwest. The area is densely covered by undergrowth, which renders prospecting difficult. The dip needle has been successfully used within this area, and the deposit just described was located by it.

CHARLES PROSPECT.

The Charles property is about 1 mile southeast of the Mammoth group and 5,000 feet from tidewater, at an elevation of 380 feet. It was located in May, 1907, and only a small amount of work has been done on it. The mineral body exposed in a cut 20 feet long and 10 feet deep consists of chalcopyrite masses associated with some magnetite in a garnet gangue which replaces the greenstone tuff country rock. Diorite occupies the hill just west of this prospect, but was not exposed near the mineral body. Dikes of diabase crosscut the ore body and are evidently of later origin. Besides the copper, the ore is said to carry high values in both gold and silver.

VENUS GROUP.

The Venus group of claims is on Iron Creek 1¼ miles from the head of Kasaan Bay and about 1 mile south of the Rush & Brown mine. This property was located in 1904 and a magnetic survey made. Within the area of maximum attraction a pit was sunk and a trench 50 feet in length was made through the overlying débris, exposing the magnetic deposit. Below these surface excavations, which are at an elevation of 250 feet, a tunnel 75 feet in length has been driven which crosscuts 50 feet of débris and 25 feet of country rock, and at its

face exposes ore. The country rock is an indurated greenstone tuff with interstratified quartzite beds, the ore occupying a shear zone. Associated with the ore are considerable sphalerite and pyrrhotite, with quartz and calcite as gangue minerals.

PROSPECTS ON TOLSTOI BAY.

CHARACTER OF THE ROCKS.

On the north coast of Kasaan Peninsula, adjacent to Tolstoi Bay, which affords good anchorage, much prospecting has been done and numerous locations have been made, but none of the properties have been developed beyond the prospect stage. The small promontory here is composed largely of the diorite intrusive masses, which are exposed at Tolstoi Point and along the eastern slope of Tolstoi Mountain. On the western slope and along the east shore of Tolstoi Bay greenstone tuff, sandstone, and conglomerate and a few strata of limestone are exposed. Both the bedded and the intrusive rock masses are crosscut by dikes of porphyry and diabase. The ore bodies are contact-metamorphic deposits similar to those at the mines in the southern part of the peninsula. They are lenticular masses of magnetite carrying chalcopyrite and associated with garnet, epidote, calcite, and quartz, inclosed in the bedded rocks near the intrusive granodiorite contact.

IRON CAP GROUP.

The Iron Cap property, also known as the Mahoney group, consists of two claims on the northwest slope of Tolstoi Mountain at an altitude of 1,000 feet, reached by a trail 1½ miles long starting from a cove 2 miles southwest of Tolstoi Point. In 1901 the property was prospected to a considerable extent by open cuts along a gulch and by several hundred feet of diamond-drill holes, but since that time it has been idle. The country rock consists principally of greenstone tuff and a fine conglomerate intruded by syenitic dikes of considerable width, which are apparently related to the ore deposits. Three ore bodies have thus far been located, the largest 20 feet wide and traceable for 50 feet, the major axis striking N. 45° W. A second ore body, separated from the first by a 30-foot dike of altered syenite, is 12 feet wide and is limited on the footwall side (to the southwest) by a fault plane showing a considerable seam of gouge; toward the hanging wall it grades into a garnet-epidote contact rock. The third ore body, which lies just above the other two at an elevation of 1,080 feet, appears to be a flat-lying magnetite deposit only a few feet thick.

WALLACE GROUP.

The Wallace group includes four claims on the southeast slope of Tolstoi Mountain at elevations between 800 and 1,600 feet. At several places on this property small scattered masses of copper ore are exposed, but at no place have the explorations been sufficient to determine the extent of these deposits. The uppermost ore bodies found have been opened by a short tunnel which exposes a vein of garnet-epidote rock containing chalcopyrite. This vein strikes N. 15° W. and dips 20° SW. The lower openings expose a magnetite-chalcopyrite ore, but the bodies do not appear to be extensive.

TOLSTOI GROUP.

The Tolstoi group of claims is south of the Wallace group, just below the summit of Tolstoi Mountain. The ore bodies are low-grade magnetite-chalcopyrite masses similar to those on the Iron Cap group, but they have not been so extensively prospected. Only the required annual assessment work has been done on this property.

BIG FIVE CLAIM.

The Big Five claim lies half a mile east of Tolstoi Bay, on the trail to the Iron Cap group, at an elevation of 370 feet. In 1908 a tunnel 50 feet long and a shaft exposed scattered masses of chalcopyrite, pyrrhotite, and pyrite, in a gangue of garnet, epidote, and calcite. The mineralized

mass is 10 feet wide and is a replacement deposit in limestone. Many slipping planes marked by gouge seams traverse both ore body and country rock. Assessment work only is done on this claim each year.

IRON ORE.

The only iron ore found in Kasaan Peninsula and the Copper Mountain area is magnetite, which occurs in large bodies along contacts of diorites and limestones. No special study has been made of these deposits, which have been developed only in connection with the mining of the copper ores. In the foregoing descriptions of the copper deposits, however, numerous references are made to the occurrence of magnetite.

The amount of magnetite shown at the surface is very large, and most of the ore is believed to contain no phosphorus or other detrimental impurities. The work at some of the copper mines has exposed a considerable quantity of magnetite, which carries from one-half to one and a half per cent of copper but which can not now be mined profitably as a copper ore. If the iron could be utilized, however, the copper, which could be separated magnetically after crushing, would furnish an additional source of profit. The utilization of these iron ores would seem to be a metallurgical problem, as there can be no question that they occur in quantities that should make them commercially valuable.

GENESIS OF THE ORES.

GENERAL PRINCIPLES.

In considering the probable source of the metal-bearing minerals that formed the ore deposits and of the mineral-bearing solutions that brought them from their original source and deposited them, with other minerals, in the fissures in the rocks, it should be remembered that, as in most other problems of this sort, certain theories or hypotheses as regards a supposed underlying igneous magma, the activities of mineral solutions, the precipitation of ores, and the metamorphic agencies and action are based on meager evidence. These hypotheses, however, appear to afford the most probable explanation of the condition now existing. The determination of the origin of an ore deposit is not only of scientific interest but of economic importance, for on this determination the miner must base his conclusions as to the depth to which the workable ore may extend and as to whether the ore will become more or less valuable with increase of depth. In most regions the workable deposits of copper ore are concentrations formed by circulating waters, generally of atmospheric origin, which have leached lean original ores and concentrated them as richer ore bodies in the immediate vicinity. On Copper Mountain and on Kasaan Peninsula, however, only deposits containing original or primary ores are found; few or no secondary ore deposits have been discovered.

The contact deposits are the principal valuable ores in these two areas and as they were formed dirrectly by metamorphic processes a discussion of these processes is necessary.

METAMORPHISM PRIOR TO THE GRANITIC INTRUSION.

The metamorphic changes in the stratified rock in the Copper Mountain area and on Kasaan Peninsula have already been described. Such changes were due primarily to heat, pressure, and solution and probably were intensified by the overburden of rock strata that has since been removed by erosion and by mountain-building forces or shrinkage of the earth's crust that caused lateral compression and folding of the beds. These forces produced what is known as regional metamorphism, causing a partial crystallization of the limestone beds, an induration of the gray-wacke, quartzites, and conglomerates, and a partial recrystallization and the development of schistosity in the more tuffaceous and argillaceous beds.

CONTACT METAMORPHISM.

DEFINITION.

In the districts under discussion the metamorphism of the intrusive igneous rocks and of the rocks they intruded is widespread and the processes that were involved in the changes

that occurred are numerous. These complicated phenomena are classed under the term "contact metamorphism," a term that covers the mutual effects of the action on the intrusive and the intruded rocks.

The action of an intrusive mass of molten rock—an action that affects both intruded and intrusive rock—is in part recrystallization and in part replacement by added material. This action has its maximum effect at the contact of the intrusive masses and decreases with increase of distance from the contact.

CAUSES OF CONTACT METAMORPHISM.

Contact metamorphism is due largely to the action of superheated solutions derived from the eruptive magma and forced into the rocks, where it produced recrystallization, generally without notable addition or subtraction of material except in contact deposits, which represent an extreme type of metamorphic action and whose metallic content is supposed to have been contained in the superheated aqueous solutions. The presence of superheated steam or water in eruptive magmas is referred to by Gautier,[1] who makes the following statements:

> Geological observations in all parts of the world show that thermal waters are usually related to ancient or modern volcanoes and that they issue from fissures of the same character as those occupied by metalliferous veins or igneous dikes. * * * [The quantity of water set free when granite is brought to a red heat is at least 25,000,000 to 30,000,000 tons (or 2½ to 3 per cent of its volume) for each kilometer of this rock which is the least rich in water.] Thus the gases which I have extracted from rocks are composed of the same constituents as the volcanic gases. The vapor of water, free hydrogen, and carbon dioxide predominate in both, and both contain carbon monoxide, marsh gas, nitrogen, a little hydrogen sulphide, and traces of cyanogen and of petroleum compounds. This analogy of composition suggests an analogous origin.

Lindgren[2] makes the following statement:

> Turning now to the large class of "epigenetic" deposits in which the metal is of later origin than the surrounding rock and has been introduced by agencies foreign to the rock itself, the first division which should receive attention is that of the contact-metamorphic deposits. In these the ores replace limestones or, more rarely, other sedimentary rocks, their substance is beyond reasonable doubt derived from metallic emanations from intrusive magmas, and their occurrence is closely connected with the actual contact with these intrusives, although they may extend for a couple of thousand feet away from the igneous rock. The deposits which generally contain magnetite and chalcopyrite and which usually are poor in gold and silver were formed at a considerable distance below the surface, probably never less than 1,000 feet, and there is, as far as known, no other limit in the depth at which they can be formed except that the heat must not be so high as to fuse the sedimentary beds.

In another paper on ore deposits and physical conditions Lindgren,[3] writing of ore deposits due to contact metamorphism of sediments by intrusive igneous rocks, says:

> These deposits, which are almost exclusively of metasomatic origin, are apparently caused by replacement of calcareous rocks by very hot solutions given off by the cooling magma. These solutions were probably above the critical temperature and thus really in a gaseous condition.

Spurr[4] writes:

> All rocks contain water, but the molten material contains more than the resulting rock. Most of this water is expelled at the moment of solidification, together with certain gases and a great variety of other materials held in solution. When rocks cool at the surface, the escaping water forms the clouds of steam, highly charged with gases and minerals, which issue from fissures, and when they solidify below the surface the waters and gases may be forced into the inclosing rock, producing that recrystallization and rearrangement of its constituents which is called contact metamorphism.

Kemp[5] makes the following statement in regard to magmatic waters:

> That the floods of lava which reach the surface are heavily charged with them there is no doubt. * * * There is no reason to believe that many of the igneous rocks which do not reach the surface are any less rich, and when they rise so near to the upper world that their emissions may attain the surface we must assign to the resulting waters a very important part in the underground economy.

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[1] Gautier, Armand, The genesis of thermal waters and their connection with volcanism: Econ. Geology, vol. 1, No. 7, pp. 688–697, 1906. Translation by F. L. Ransome of La genèse des eaux thermales et ses rapports avec le volcanisme: Annales des mines, 6th ser., vol. 9, pp. 316–370, 1906.

[2] Lindgren, Waldemar, Ore deposition and deep mining: Econ. Geology, vol. 1, p. 36, 1905.

[3] Lindgren, Waldemar, The relation of ore deposition to physical conditions: Econ. Geology, vol. 2, No. 2, pp. 105–127, 1907.

[4] Spurr, J. E., Relation of rock segregation to ore deposition: Eng. and Min. Jour., vol, 76, p. 54, 1903.

[5] Kemp, J. F., The problem of metalliferous veins: Econ. Geology, vol. 1, No. 3 (December–January, 1905–6) p. 229.

Lincoln,[1] writing on magmatic emanations, makes the following statements:

> Magmas contain certain substances which decompose or interact unless prevented by pressure or cooling. These generators give rise to primary magmatic emanations. Cooling or pressure or both cooling and pressure prevent the complete destruction of the generators, hence igneous rocks contain repressed emanations which may be expelled by heating them to red heat at atmospheric pressure.
>
> Intruded magmas by heating the adjoining rocks induce secondary emanations which consist of part of the potential emanations of these rocks. The ratio of primary to secondary emanations is an unknown quantity.
>
> Magmatic emanations which are expelled as gases and vapors become at the ordinary temperatures of the earth's surface solids, liquids, and gases. The principal gases are carbon dioxide, methane, hydrogen, hydrochloric acid, hydrogen sulphide, sulphur dioxide, nitrogen and oxygen with less carbon monoxide and ethane and a very little hydrofluoric, hydriodic, and hydrobromic acids. Water is the only important liquid, and it makes up a large percentage of the total emanation. The solids are chiefly chlorides and sulphates of the alkalies and alkaline earths and of iron, together with a much smaller quantity of metals and mineralizers.

DEVELOPMENT OF CONTACT METAMORPHISM.

As has already been noted, the intruded rock strata had been subjected to regional metamorphism prior to the intrusion of the igneous masses, which cooled and solidified at a considerable depth below the surface. It is therefore reasonable to suppose that the heat contained in the igneous rock masses at the time of their intrusion was gradually, though extensively, imparted to the intruded rock beds. It is reasonable to assume that while losing their heat both the intrusive and intruded rocks contracted somewhat at their contacts, leaving small open spaces and fissures in the contact zone, which permitted the metamorphic action to extend still farther from the contact. Around the intrusive contacts, especially at points where the line of contact is irregular, many cracks and fissures were formed, and along these local fractures the effects of contact metamorphism are most pronounced. The emanations from the igneous magma or mineralizing solutions ascended along these openings, dissolving and precipitating minerals and forcing themselves outward into the more or less porous wall rocks, where they caused replacement of the original mineral components of the rocks. The deposition of minerals from these solutions is attributed to supersaturation resulting from the decrease in the temperature and pressure of the solutions as they came into contact with colder rocks, but was probably to some extent due to precipitation of elements that entered the solutions on their upward course.

ORIGIN OF ELEMENTS CONTAINED IN MINERAL SOLUTIONS.

Whether the elements contained in the mineral solutions were derived directly from the magma from which the solutions emanated or whether they were derived from the rocks through which the solutions passed is not known, but it is probable that certain elements, such as iron, sulphur, and copper, found in the contact deposits and not in the adjacent rocks, were contained originally in the heated solutions. The lime and magnesia in the contact rock, however, are believed to have been derived by the solutions from the calcareous rocks through which they passed; the silica, alkalies, and alumina which have entered into the composition of the contact rock may, on the other hand, have been leached from the diorite.

METAMORPHIC EFFECTS ON THE INTRUDED ROCKS.

The character and extent of the contact metamorphism of the intruded rocks have been determined by many factors, such as the temperature, composition, depth, size, and form of the intrusive mass and the composition and porosity of the intruded rock strata. Though the results of metamorphism should be similar under similar conditions the amount of alteration varies widely from one point to another along the same contact and is besides dependent on the local development of fractures and fissures in the rocks along which the solutions circulated and produced the alterations noted. Extensive replacement of rock beds at certain localities and practically none at others indicates that the metamorphism is due mainly to the action of

[1] Lincoln, F. C., Magmatic emanations: Econ. Geology, vol. 2, No. 3, pp. 273, 274, 1907.

mineral solutions that were introduced along the contacts, and not so much to the immediate effects of heat and chemical reactions in the intruded rocks themselves at the time of the igneous intrusion.

The mineral solutions penetrated the sedimentary rocks most freely and produced metasomatism most readily along calcareous layers in the strata, completely altering them. In such beds diopside, garnet, epidote, and feldspar were formed, and in some places pyrite, pyrrhotite, and chalcopyrite are scattered through them. Limestone beds that lay at the contact are changed to marble and contain tremolite. Generally the line of contact with the limestone is sharp and is marked by the development of granules of diopside next to the intrusive rock and of tremolite in fine needles in the limestone. The contact rock contains included fragments and small masses of limestone and in places considerable calcite, which may have been formed by solution and reprecipitation of the limestone.

The calcite crystals usually form a matrix including diopside and garnet in irregular grains, and in some places appear to be the last mineral formed.

In the more porous strata, such as the schists and graywackes, there is not the sharp contact between the contact rock and the intrusives, except where the intrusive fills fissures that extend into the contact rock. These rocks appear to have been impregnated with mineralizing solutions which deposited in them garnet, epidote, diopside, feldspar, hornblende, wollastonite, tremolite, calcite, and some quartz, the first four minerals being confined to the contact zone and the last five minerals lying farther away from the contact. To what extent these minerals were formed by metasomatism of the rock beds without addition of material is difficult to determine; nor is it possible to say to what extent new material was introduced by the solutions.

METAMORPHIC EFFECTS ON THE INTRUSIVE ROCKS.

The direct changes caused by the adjacent igneous mass are relatively slight in comparison to the changes caused by the mineral solutions that passed along the contact and impregnated the rocks along the channels they traversed. The changes noted are essentially those of metasomatism and occurred after the intrusive mass had solidified. Greater changes were made in the intrusive than in the intruded rocks. In many places metasomatism caused by the solutions has been so great that the intrusive rock itself is entirely transformed into contact rock. Generally, there is no sharp line of division between the contact rock and the intrusive mass, the two grading into each other. In certain places fissure veins of contact rock enter the intrusive rock, but they do not extend far from the contact zone. The wall rocks around the contacts show here and there a slight veining, a few inches to a few feet wide. These veins are pegmatitic, consisting of large amphibole and plagioclase crystals with some pyrrhotite, diopside, and calcite. The feldspar in the diorite itself has been altered to scapolite, the alteration being attributed to the action of the mineralizing solutions. Where wide zones of contact rock occur the intrusive rock has been most altered and has contributed in large measure the material that makes up the contact rock, as is shown by analyses of the unaltered diorite, of the altered diorite at the contact, and of the contact rock itself, which are remarkably similar for rocks that differ so widely in mineral composition.

The main effects of the contact metamorphism on the diorite have been to change the feldspar (essentially alkaline) to scapolite and the hornblende to diopside and epidote. On passing from the unaltered diorite toward the contact one may note that the granitic texture gradually disappears, the rock assumes a dull and somewhat bleached appearance, the altered feldspar aggregates are separated by pale-green diopside and aggregates of epidote, and finally that the rock seems to be amorphous, of a pale-pink to greenish color, and felsitic in texture. This felsitic rock is made up almost entirely of scapolite, light-green diopside, some epidote in tufted aggregates, garnet in patches (in places connected with veins), and scattered particles of calcite. In the contact rock the original feldspar and ferromagnesian minerals are entirely replaced, though the rock still contains unaltered titanite crystals in considerable amounts, which were originally in the diorite, this occurrence emphasizing the fact that the alteration of the diorite

has been extensive and that in certain places, at least, the contact rock is only a replacement of the diorite. The first alteration of the diorite was evidently accompanied by the deposition of pyrite, pyrrhotite, and molybdenite. Diopside seems to occur where pyrite is present and calcite with hornblende accompanies the molybdenite and magnetite.

DEVELOPMENT OF THE CONTACT ROCK.

Microscopic study of numerous specimens of the contact rock shows that it is in part altered wall rock, mostly limestone, and in part altered diorite, and that some of it has been formed by the filling of fissures in these rocks. The interior parts of several specimens of limestone that were included in the contact rock and of ores of the Jumbo mine are a finely granular white limestone containing considerable dolomite, which is bordered by a zone, a few centimeters wide, in which tremolite is abundant, and just outside of this zone is another zone, several inches wide, in which tremolite disappears and diopside is abundant. Garnet may accompany the diopside, and at a distance from the limestone may take its place, passing into a vein deposit with garnet druses. Usually, however, a deep-green amphibole appears at the outer border of the diopside zone, and beyond it the ores, chalcopyrite and pyrrhotite, become abundant, passing into solid masses of sulphide. Much of the rock of the contact zone consists of garnet and diopside with calcite, the diopside scattered and the garnet in part scattered and in part filling fissures.

The following analyses show the chemical composition of the several types of rock found at the Jumbo mine. The analyses were made from chips representing every type.

Analyses of specimens of rock from the Jumbo mine.

	1. Diorite.	2. Altered diorite.	3. Contact rock.	4. Limestone.	5. Garnet.	6. Orthoclasite.	7. Diopside.
SiO_2	59.44	46.57	39.51	0.61	35.18	62.03	55.12
Al_2O_3	17.40	13.51	5.87	.30	5.15	16.39	.40
Fe_2O_3	3.30	2.92	8.54	.48	25.05	.72	.....
FeO	2.77	2.73	3.40	.....	.40	.86	1.12
MgO	1.81	2.85	5.08	8.00	.09	1.60	18.15
CaO	6.51	19.92	29.42	46.45	33.36	3.60	25.04
Na_2O	4.22	2.33	1.00	.....	.....	1.08	.45
K_2O	3.12	2.52	.64	.22	.....	12.38	.02
H_2O-	.06	.33	.33	.....	.42	.24	.17
H_2O+	.56	.53	.62	.....	.....	.61	
TiO_2	.66	.64	.29	.....	.....	.53	.....
CO_2	None.	3.40	3.68	44.07	.....	.....	.....
P_2O_5	.28	.27	.07	.....	.....	.13	.....
SO_3	.....	.....	Trace.	.....	.....	.....	.....
S	.02	.....	.....	.06	.....	.....	.....
MnO	.17	.40	.62	.03	.....	.....	.....
BaO	.07	.....	.....	.....	.....	.....	.....
SrO	.05	.....	.....	.....	.....	.....	.....
FeS_2	.....	.....	.64	.....	.....	.....	.....
MoS_2	.....	.78	.....	.....	.....	.....	.....
	100.44	99.70	99.71	100.22	99.65	100.17	100.47

1 to 6 are analyses of rock from Jumbo No. 4 claim. Analysts: 1, 4, George Steiger; 2, 3, R. C. Wells; 5, W. T. Schaller; 6, Chase Palmer.
7 is a published analysis (Dana, E. S., System of mineralogy, 6th ed., p. 359, 1892) of a diopside at a diorite limestone contact at De Kalb, N. Y.

The analyses indicate that in order to derive a considerable part of the contact rock from the limestone by the development of such minerals as are abundant in the contact rock it would be necessary to add much silica, considerable ferric oxide, and some alumina, and to subtract a corresponding quantity of lime and carbon dioxide. It is assumed that solutions passing from the cooling intrusive rock performed these changes. The analysis of the altered diorite shows that it has lost such constituents as have been gained by the limestone and that it has gained much lime and carbon dioxide, constituents that the limestone has lost.

A specimen of the altered diorite at the contact with diopside-garnet-calcite rock had lost all its free quartz and most of its plagioclase, and in place of these it contained abundant calcite, considerable garnet, and much diopside. Its orthoclase was still present in nominal amount. Small patches of molybdenite accompanied the calcite. The molybdenite had clearly been introduced, for it was abundant in the adjacent contact rock. If this rock had lost orthoclase and had gained a little more garnet it could not be distinguished from the contact rock developed

from the limestone. The analyses of the diorite, altered diorite, and contact rock show clearly that by subtracting the elements of the alkali feldspar—silica, alumina, and alkali—and adding the constituents of the limestone and of garnet the diorite could be transformed into the contact rock. The less altered diorite in places shows little change except the replacement of plagioclase by scapolite and the introduction of calcite.

Irregular veinlike bodies, which are generally the latest phase of the contact rock, vary in composition from pure garnet and nearly pure diopside to mixtures of orthoclase, calcite, and epidote, with or without diopside and garnet. A specimen from the Sultana claim simulates very perfectly the texture of coarse diabase. It contains long, lathlike intersecting crystals of nearly colorless diopside in a matrix of dark garnet and calcite in small amount in place of the garnet, suggesting that the diopside developed in limestone and that the garnet replaced [1] this limestone. The abundance of orthoclase unassociated with quartz is especially noteworthy. It occurs in very irregular branching masses a few inches wide, generally pink in color and very fine grained, even under the microscope, and consisting of orthoclase and calcite and masses of more coarsely crystalline epidote or diopside. These masses are probably closely related in origin to the syenitic form of the diorite, described as diopside-orthoclasite, an analysis of which is given in the table on page 40 (analysis 6).

Tremolite and diopside are found along the contact of the intrusive rock with massive limestone; wollastonite appears near the shaly limestones and is accompanied by much garnet and little or no diopside. The bands of garnet are sharply separated from the bands of wollastonite, the garnet probably occupying the place of shaly bands and the wollastonite that of the purer limestone. The absence of both tremolite and diopside near the shaly limestone is probably due to its lack of magnesia. Both these minerals are calcium-magnesium silicates, but wollastonite is a calcium silicate.

The contact rock is richer than either of the rocks inclosing it in ferric oxide, which is abundantly present in the garnet, and must have been introduced by the solutions that caused the contact metamorphism and the deposition of the ores.

The analysis of the contact rock in the contact deposits on Kasaan Peninsula does not show a great change in composition (see analysis, p. 83) because of the similarity in composition of the intrusive diorite and the intruded graywackes. The ore bodies, however, show that the copper and iron oxides and sulphides were introduced by the mineral-bearing solutions.

DEVELOPMENT OF THE ORE MINERALS.

The ore minerals occur chiefly near the limestone contact. With garnet and diopside, pyrrhotite and chalcopyrite are locally abundant in the recrystallized limestone. These ore minerals ramify in a meshlike structure through the calcite that incloses the diopside and garnet, and, in places, the amphibole. Finely outlined crystals of diopside are scattered thickly through the ore at some places in precisely the same manner as in the limestone. In other places, as at the Sultana claim, the ore occurs in parting and cleavage planes in shattered crystals of diopside and in veinlets of garnet. In a specimen from the Jumbo No. 4 claim the garnets that occur in the compact limestone of the wall rock are surrounded by thin shells of chalcopyrite.

Chalcopyrite occurs sparingly in the altered diorite in close association with calcite, which has been introduced into the diorite. Chalcopyrite and pyrrhotite are irregularly distributed in veinlike masses through that part of the contact zone which consists largely of garnet, diopside, orthoclase, calcite, and epidote. As developed in the contact rock this ore replaces calcite but not to any notable extent the other minerals.

In certain places the sulphide ores occur in distinct veins in the contact zone associated with epidote, quartz, orthoclase, calcite, a dark amphibole, magnetite, and, to less extent, diopside and garnet.

[1] The term "replacement" is used in this report in its broadest sense, meaning "taking the place of," without implying that solution and deposition have been practically simultaneous. However, the microscopic evidence that the plagioclase of the diorite altered directly to scapolite is as clear as could be desired.

PROGRESS OF MINERALIZATION.

The following view of the progress of mineralization in the contact zones is favored by the evidence. In the limestone tremolite (or wollastonite) and diopside were formed by the introduction of silica; later, and in part contemporaneously, garnet was formed by the combination of the lime (already present) with silica, ferric iron, and alumina, introduced by solution. While the quartz and feldspars were being removed from the diorite calcite, garnet, and pyroxene (diopside) were added. Afterward chalcopyrite and pyrrhotite replaced part of the calcite in the contact zone without notably affecting the other minerals. Later the fissures, which probably held the solutions during the period of active metamorphism, were filled with pyrite, chalcopyrite, magnetite, and the other minerals above enumerated. Finally upon the older vein minerals were deposited notably zeolite and calcite.

PROBABLE LIMITS OF TEMPERATURE.

The probable limits of temperature between which contact metamorphism took place can not be very closely determined. Wollastonite, which, for reasons already stated, appears to have been one of the first minerals formed in the contact zone, can not exist above 1190° C.[1] The garnet, some of which probably formed almost contemporaneously with the wollastonite, is a variety having distinct double refraction. Experiments made with this garnet by Dr. Merwin at the Geophysical Laboratory of the Carnegie Institution of Washington show that it loses its birefringence after it has been heated for a few hours at about 800° C., and does not regain it after several hours heating at 600° C. This fact indicates that most of the metamorphism took place at temperatures lower than 800° C.

Quartz occurs in the contact zone only in veins. Tests made on some of this vein quartz by F. E. Wright, according to the method described by Wright and Larsen,[2] indicated that it was formed at temperatures below 575° C. The vein quartz was formed, however, during the last stages of metamorphic activity.

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PROFESSIONAL PAPER 88

LAVAS OF HAWAII AND THEIR RELATIONS

BY

WHITMAN CROSS

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LAVAS OF HAWAII AND THEIR RELATIONS.

By WHITMAN CROSS.

INTRODUCTION.

In 1902 I made a reconnaissance of certain parts of the Hawaiian Islands for the United States Geological Survey, with the hope of adding to the meager petrographic knowledge of this volcanic group. Although many geologists have visited these islands, interest has attached largely to the volcanic phenomena, and there is a singular dearth of important petrographic literature concerning the lavas themselves. The reason for this dearth I did not appreciate until I had visited the islands.

The lavas of Hawaii are generally referred to as basaltic. Many of them are plainly so, containing olivine and augite in prominent crystals. By far the larger number of the rocks are, however, chiefly black and aphanitic and seemingly of few varieties. The collector, be he layman or petrographer, is unfortunately likely to assume that they are all basaltic and to limit his collection to a few marked varieties. The truth is that there is a very considerable range in composition in the lavas of Hawaii, and systematic study will add many types to those now known. It will be highly desirable, however, to determine the rocks during the progress of field work, so that the types of unusual character may be traced out whenever found.

Among the rocks collected by me are a number of types that are rare or not mentioned in the literature of Hawaiian lavas, but for most of these types I am unable to give data of distribution, because their unusual character was seldom recognized in the field. As it now seems probable that more thorough investigation of the islands may be undertaken, it appears desirable to give such petrographic data as the collection of 1902 affords so that they may be of some assistance to future workers.

An occurrence of trachyte on the island of Hawaii, first observed in 1902, has already been described.[1]

Besides describing rocks I collected myself I shall briefly review the scattered data of earlier literature concerning Hawaiian lavas, in order to provide a basis for a preliminary discussion of the provincial characters of these rocks, especially with relation to their chemistry and mineralogy. The Hawaiian magmas, imperfect as present knowledge concerning them may be, throw light on several interesting petrographic problems of the day.

The principal petrographic descriptions of Hawaiian lavas are those by E. Cohen (1880), O. Silvestri (1888), E. S. Dana (1889), and F. Möhle (1902). None of the rocks described were collected by the petrographers describing them, and only a part of one collection, that studied by E. S. Dana, was obtained by a geologist. Most of the lavas studied by Cohen were collected by Dr. William Hillebrand, a botanist, the father of Dr. W. F. Hillebrand, who analyzed some of the rocks to be described. Silvestri's material was gathered by Prof. P. Tacchini, an astronomer. Möhle's studies pertain to a collection made by Prof. H. Schauinsland, a zoologist. Under these circumstances there is naturally a lack of precise information concerning the local source and manner of occurrence of many interesting types, and much of the material is of value only in a general survey of the petrology of the islands.

It is an accepted generalization concerning the Hawaiian Islands that they have been built up by a long-continued series of volcanic eruptions beginning at a point far west of the principal islands of to-day. Hawaii, the largest and most recent island, with its active volcanoes, is at the southeastern extreme of the row of island centers of eruption.

[1] Cross, Whitman, An occurrence of trachyte on the island of Hawaii: Jour. Geology, vol. 12, pp. 510–523, 1904.

Whether the earliest eruptions began at many points at about the same time, as J. D. Dana supposed, or whether the oldest center is at the northwest limit of the chain, is a question not entirely settled, it seems to me. The oldest volcanoes known are now represented by islets or mere reefs of basalt rising but a few feet above the sea. Possibly the earliest volcanoes of this chain have wholly disappeared through cataclysmic disturbances or long-continued erosion, such as has greatly reduced the bulk of even the more recent islands.

With this long history of volcanism along one line of weakness in the ocean bottom it is of interest to study the series of lavas of each center and compare those of different centers. For this reason, as well as for convenience, the rocks will be taken up beginning with those of the older centers and proceeding, in order, to those of Hawaii.

I have had access to other important collections besides the rocks obtained by myself. A large collection of lavas from Oahu, made by Prof. C. H. Hitchcock for the National Museum, and a small collection from Mauna Kea, made by E. D. Preston, were generously placed at my disposal by Dr. G. P. Merrill, curator of the department of geology in the museum. Dr. Merrill has himself described the Preston material.[1] I am further indebted to the courtesy of Prof. E. S. Dana for an opportunity to examine the thin sections of Hawaiian lavas described by him. He also kindly furnished material for a chemical analysis of a soda trachyte from Maui.

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PETROGRAPHY.

THE LESSER ISLANDS.

Very little is known concerning the small islets lying northwest of Kauai. They are reported to consist of coral rock or sand with a foundation of basalt. The only petrographic details published are given by Möhle [1] on the basis of Schauinsland's collection from Laysan and Necker islands. Laysan is about 800 miles northwest of Kauai. This island rises only 30 feet above the sea and consists superficially of coral limestone, but blocks of olivine-plagioclase basalt occur a little below sea level. This rock and two beach pebbles are represented in the collection. The pebbles differ in character, one being a decomposed basalt and the other a feldspathic rock with magnetite, little olivine, and rare augite grains. The latter rock has a trachytoid texture and is compared by Möhle with a soda trachyte from Maui, to be described in the present paper. The character of the feldspar of the Laysan rock is not stated, but it is no doubt a highly calcic plagioclase, as the rock is said to contain but 44.98 per cent silica.

Necker Island, 330 miles from Kauai, is 0.7 mile long and rises 300 feet above the sea. The principal rock of this island, according to Möhle, is an olivine-plagioclase basalt of holocrystalline porphyritic texture. Two dike rocks found on the island are also olivine-plagioclase basalts of doleritic texture, characterized by violet augite and ilmenite.

ISLAND OF KAUAI.

OCCURRENCE AND SOURCES OF MATERIAL STUDIED.

Kauai is the oldest of the larger islands of the Hawaiian group. It embraces about 547 square miles and has a general round outline. The island consists mainly of a single deeply dissected volcanic pile, the present summit of which, called Waialeale, has an elevation of 5,080 feet. From this center radiate deep canyons, the principal ones being on the north, west, and south sides. In the walls of these canyons and in the great sea cliffs of the northwestern shore are excellent exposures of the basaltic complex which, so far as known, makes up the entire island beneath the surficial materials.

The structure of Kauai is extremely simple and is typical of a basaltic volcano. All the canyons exhibit a series of dark basaltic flows dipping gently away from the general center of

[1] Möhle, F., Neues Jahrb., Beilage Band 15, pp. 90–93, 1902.

the island. The flows are diverse in thickness, their limits being clearly defined by breccia, scoria, or tuff zones, separating the more massive rock.

The rocks to be described were all collected by me and came from canyon branches of Waimea, Makaweli, and Hanapepe rivers, which head to the south or southwest of Waialeale and cut deep into its mass. Some of them came from lava flows, others from dikes, and still others from bowlders in the stream beds, selected to exhibit recognizable varieties which must occur in place in the upper parts of these valleys.

After the principal part of the erosion by which the strongly marked topographic features of Kauai were produced came minor volcanic outbursts at many places. By far the larger number of these comparatively recent eruptions were explosive in character, ashes being scattered over a large part of the island. Many of the best plantation soils of the lowlands are derived from these ashes. Small lava flows also issued from some of the recent vents.

The rocks collected embrace a considerable range of olivine-plagioclase basalts, olivine-free plagioclase basalt, limburgite, nepheline-melilite basalt, and gabbro, and they will be described under these heads.

OLIVINE-PLAGIOCLASE BASALT.

General characters.—The olivine-plagioclase basalts of Kauai exhibit a great range of textures. Many of them are dark, almost black rocks in which few, if any, mineral particles can be recognized by the unaided eye. Such aphanitic phases are either dense or variably vesicular. Some fine and nearly even-grained basalts contain many megascopically determinable particles of olivine, augite, and feldspar.

A porphyritic texture is not uncommon and is as a rule due to relatively large olivine phenocrysts. In some rocks olivine occurs in fine fresh crystals which exceed 1 centimeter in diameter. The crystal form is often nearly perfect, but curved partings cause the phenocrysts to resemble perlitic grains. Rocks rich in large olivine phenocrysts are in many places also notably vesicular. Especially in such rocks the parting surfaces of olivine are likely to exhibit brilliant iridescent colors. The abundance and large size of the olivine phenocrysts are the most striking features of the basalts of Kauai that have been examined.

From the few specimens collected it appears that both olivine and plagioclase are quantitatively very variable constituents. Augite is always abundant, but titaniferous magnetite is decidedly more subordinate than is usual in such rocks. Olivine is likely to occur in abundant phenocrysts, but some of the aphanitic facies are also very rich in this mineral. Augite is commonly present in microscopic grains and even where it occurs in distinct crystals it is inconspicuous. Plagioclase is less prominent than the mafic [1] silicates, occurring in the usual ophitic groundmass. It is as a rule more calcic than labradorite.

In general the plagioclase basalts of Kauai are, then, of common varieties. They are notably rich in titanic acid, which occurs in magnetite and in pink or purplish augite, but the total amount of the iron oxide is small.

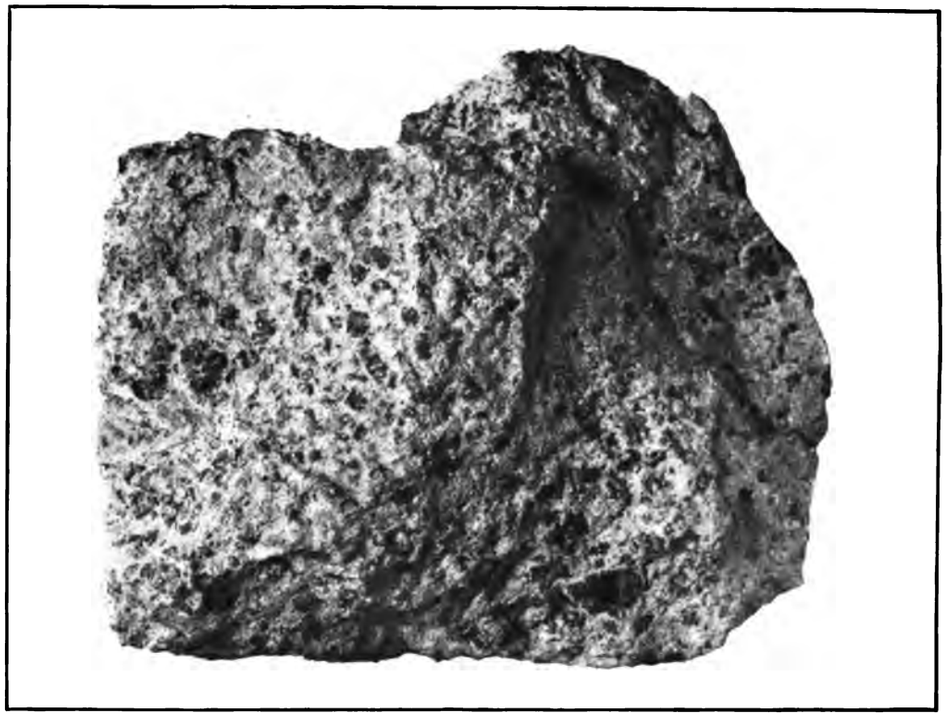
Chemical composition.—The olivine-plagioclase basalts of Kauai are of varieties known in many parts of the world, but for the sake of comparison of different types and the general discussion of Hawaiian magmas two contrasting basaltic types were submitted to analysis, both from Olokele Canyon, the main branch of the Makaweli.

The composition of a nearly holocrystalline, minutely vesicular ash-gray olivine porphyry or chrysophyre, to use J. D. Dana's expressive field term, is shown by analysis 31, in the accompanying table, made by W. T. Schaller. The rock occurs on the south side of Olokele Canyon, near tunnel 24 on the line of the Olokele ditch, which was in course of construction in 1902.

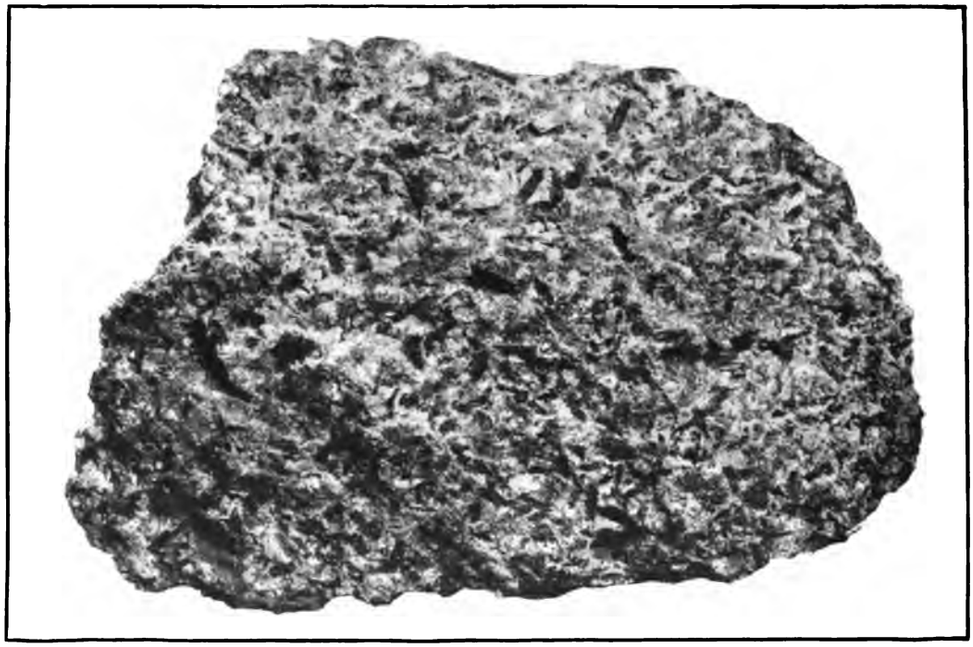
Plate II, *A*, illustrates the texture of the specimen from which the material for analysis was taken. All the visible phenocrysts are olivine, of strong green color. They are almost perfectly fresh; some exceed 1 centimeter in diameter and none are as small as the augite in the groundmass. These olivine phenocrysts constitute from 20 to 25 per cent of the rock.

The vesicles are scarcely recognizable in the illustration. They are irregular in form and contain, as peculiar to them, only two or three recognized minerals. One of these occurs in

[1] *Mafic* is a modal term applied to the ferromagnesian minerals of rocks. The word *femic*, often used in this sense, applies properly only to normative molecules.



A. OLIVINE-PLAGIOCLASE BASALT (CHRYSOPHYRE) AT RIM OF OLOKELE CANYON.



B. SODIC GABBRO (KAUAIITE) OF WAIALE CANYON.

BASALT AND SODIC GABBRO FROM KAUAI.

minute dull-white rhombic dodecahedrons about 0.3 to 0.5 millimeter in diameter. These crystals are scattered all through the specimen, but rarely do more than two or three occur in one cavity. Detached crystals were examined under the microscope and found to be weakly doubly refracting. They do not extinguish as units but show a plaidlike pattern between crossed nicols, due to complex twinning. Through the assistance of E. S. Larsen the index of refraction was determined to be 1.485 ± 0.003. This seemed to indicate either analcite or cristobalite. Hydrochloric acid does not attack the crystals.

For further identification of the mineral about 25 crystals, weighing in the aggregate about 1 milligram, were detached and their refractive index observed by Mr. Larsen. This material was then tested for water and silica by R. C. Wells, in the chemical laboratory of the Geological Survey. There was no loss on ignition, which, with the observed resistance to hydrochloric acid, makes it certain that the mineral can not be analcite. Ignition with hydrofluoric and sulphuric acids resulted in a loss of 85 per cent. The residue probably represents material on which these crystals were implanted. It thus appears almost certain that the mineral is cristobalite which has reverted from the original isotropic high-temperature form to the tetragonal modification existing below 175°.

Augite in minute anhedral grains and plagioclase in microlites make up the dominant groundmass, with augite in excess. The rock contains some smoky-brown intersertal glass but not as a continuous matrix. Magnetite occurs in minute very fresh grains, many of which are arranged in rows. It is presumably highly titaniferous. In many spots there is a distinct development of tridymite in wedge-shaped aggregates between plagioclase crystals, and characteristic round spherules of tridymite occur in some of the minute pores.

The rock of analysis 35, made by W. F. Hillebrand, is nearly aphanitic, very dark gray, and belongs to a flow exposed at the south end of tunnel 20 on the Olokele ditch. Examination of it with a hand lens reveals numerous yellowish-brown olivine phenocrysts. In thin section it is found to consist of plagioclase, augite, olivine, and magnetite, with a little apatite and intersertal globulitic glass in disconnected areas. Both augite and plagioclase occur in larger individuals than in the chrysophyre described above. Olivine occurs chiefly in the phenocrysts but partly in anhedral grains like those of augite. Magnetite is concentrated in a few crystals equaling those of augite in size. The fabric is ophitic.

In the general discussion (p. 74) it is shown that these basalts are very near in composition to certain others from various parts of the world.

Analyses and norms of olivine-plagioclase basalt.

Analyses.			Norms.		
	31	35		31	35
SiO_2	48.99	45.48	Orthoclase	1.67	4.45
Al_2O_3	13.73	11.87	Albite	13.62	12.84
Fe_2O_3	1.60	1.98	Nephelite	.....	2.92
FeO	10.46	9.87	Anorthite	29.19	20.57
MgO	13.53	13.28	Diopside	5.13	26.39
CaO	7.34	10.97	Hypersthene	36.82	.....
Na_2O	1.62	2.21	Olivine	7.21	24.28
K_2O	.27	.77	Magnetite	2.32	3.02
H_2O-	.10	.23	Ilmenite	3.19	3.65
H_2O+	.27	.74	Pyrite	.....	.03
TiO_2	1.73	1.90	Apatite	.30	.47
ZrO_2	None.	None.			
CO_2	.24	None.		99.45	98.62
P_2O_5	.13	.25	Rest	.73	1.17
S	.04	.....			
Cr_2O_3	.02	.08		100.18	99.79
V_2O_3	.06	.04			
NiO	.05	.04			
MnO	.20	.16			
BaO	Trace.	.04			
FeS_2	.....	.03			
	100.38	99.94			

Quantitative classification.—The position and magmatic character of the basalt of analysis 31 in the quantitative system are shown below:

Class: $\frac{Sal}{Fem}=\frac{44.5}{55.0}=0.81=III$, salfemane.

Order: $\frac{L+Q}{F}=\frac{0}{44.5}=0=5$, gallare. Symbol: III.5.4.4–5.

Rang: $\frac{K_2O'+Na_2O'}{CaO'}=\frac{29}{105}=0.28=4$, auvergnase.

Subrang: $\frac{K_2O'}{Na_2O'}=\frac{3}{26}=0.11=4$–5, auvergnose.

The rock of analysis 35 has the systematic characters expressed by the following data:

Class: $\frac{Sal}{Fem}=\frac{40.78}{57.84}=0.705=III'$, salfemane.

Order: $\frac{L}{F}=\frac{2.92}{37.86}=0.08=5'$, gallare. Symbol[1]: III′.5′.(3)4.4–5.

Rang: $\frac{K_2O'+Na_2O'}{CaO'}=\frac{43}{74}=0.58=(3)4$, camptonase-auvergnase.

Subrang: $\frac{K_2O'}{Na_2O'}=\frac{8}{35}=0.23=4$–5, camptonose-auvergnose.

This basalt is therefore in the division of the salfemanes, intermediate toward the dofemanes. It is transitional between the docalcic and alkalicalcic rangs and is therefore also transitional between the presodic subrangs, camptonose and auvergnose, of these rangs.

Relation of norm and mode in rocks analyzed.—These two rocks exhibit very notable differences in normative composition, but the analyses are by no means so strikingly different. The great variations in diopside, hypersthene, and olivine illustrate the cumulative effect of certain relatively small differences in silica, alumina, lime, and the alkalies. The normative diopside of No. 35 is more than five times that of No. 31, because the decrease of alumina in No. 35 is coincident with increase of both lime and alkalies, doubly increasing the amount of lime available for diopside. The presence of hypersthene in No. 31 is due of course to the higher silica content.

The modal composition of No. 35 is clearly not far from the normative, but No. 31 exhibits a mode differing from the norm in a very interesting manner. According to the calculation of the norm this magma contained sufficient silica to have reduced the amount of the orthosilicate olivine to 7.21 per cent had there been that free exercise of the chemical affinities generally assumed to prevail in magmatic solutions. In the magma of basalt 35 conditions were evidently much more nearly normal. The augite of basalt 31 clearly contains a considerable amount of the normative hypersthene, but about half of the hypersthene is represented in modal olivine, freeing an amount of silica which appears in tridymite and cristobalite, as has been described.

These basalts of the same center of eruption and very nearly of the same age show the effect of some undetected difference in composition or in conditions attending their crystallization from magmatic solution, which is plainly of much importance. As will be brought out in the general discussion, there is some condition, commonly realized in Hawaii, which is particularly favorable to the formation of olivine from magmas whose silica is sufficient to have produced a much larger amount of a higher silicate than is found. This is commonly shown by the presence of free silica in olivine rocks, once considered an impossibility.

The differences between norm and mode of these rocks with regard to orthoclase and nephelite are not very striking quantitatively, and possibly the small amounts of these substances shown in the norms are hidden in the residual glass. In basalt 35, however, it seems more reasonable to suppose that nephelite and orthoclase are to some extent "occult molecules," to use the suggestive term proposed by Iddings for material held in solid solution. It is well known that orthoclase may be and frequently is held in plagioclase. It has also been

[1] In the symbols expressing the quantitative classification of a rock the use of a parenthesis shows that a rock falls in a narrow transitional zone between two divisions. A prime mark indicates a less marked approach to some adjacent division. For the limits of the transitional and intermediate zones the reader is referred to the original publication suggesting these distinctions (Jour. Geology, vol. 20, pp. 554–557, 1912).

claimed by Washington and Wright [1] that 5.5 per cent of carnegieite, having the stoichiometric composition of nephelite, is held in solid solution in labradorite of the island of Linosa. The norms of many rocks show normative nephelite where no trace of that mineral can be found in the rock, and a part at least of such potential nephelite may be explained in this way. Obviously no emphasis should be placed on this hypothesis until more evidence in its favor has been produced. Plagioclase is more abundant in the norm than it seems to be in the rock, but that may simply illustrate the difficulty of correctly estimating the amount of a transparent colorless mineral in such fine-grained aggregates.

PLAGIOCLASE BASALT (POOR IN OLIVINE).

Several rocks of Kauai are notably poor in olivine while rich in calcic plagioclase and augite and retaining the usual basaltic habit. Such rocks will be called basalts, although some of them may be referable to augite andesite. So long as it is unknown whether or not the paucity of olivine is characteristic of the whole mass represented by a given specimen, and the plagioclase is at least as calcic as labradorite, it seems best to recognize the affinities of these rocks with the basalts rather than with the andesites.

One of these plagioclase basalts occurs in the eastern part of the Koloa sugar plantation, in the southeastern part of the island, in low ground near the sea. It forms a low ridge west of a pumping station. In this vicinity are several centers of ash eruption and at least one lava flow of recent date, but the relations of the flows at the locality mentioned were not determined. It is surmised that they are younger than the main basaltic complex of the island.

This Koloa rock is gray in color and contains many small irregular pores, into which project crystals of feldspar. The pronounced ophitic fabric is visible megascopically through the cleavage planes of many narrow plagioclase tablets, but the interstitial augite can not be recognized. The plagioclase plates and prisms reach 2 to 3 millimeters in length.

In thin section the rock is seen to possess a not unusual type of ophitic fabric in that the plagioclase blades radiate in rude sheaves from many centers. Augite of common character lies between the feldspars and is developed in larger individuals than in any of the olivine basalts. Olivine is very sparingly present in grains similar to those of augite. The ore constituent appears in plates rather than in grains and is probably ilmenite. Residual areas of gray globulitic glass with very delicate plagioclase microlites are scattered through the rock.

A dense dike rock in the east fork of Waimea Canyon has much less olivine than the common types but more than the last-mentioned rock.

LIMBURGITE.

In the bed of Hanapepe River below the falls, about 7 miles from the sea, there are bowlders of typical dense aphanitic limburgite, associated with the usual predominant olivine-plagioclase basalts. There, as elsewhere, the actual quantitative relations of different rocks must be determined by future work. It is believed that the various flows exposed in the walls of Hanapepe Canyon are of olivine-plagioclase basalt, but unfortunately specimens were not collected to establish this fact. It is to be supposed that the waterworn bowlders of limburgite came from above the falls.

This limburgite consists of augite, olivine, magnetite, and a subordinate dark-brown globulitic glass. The minerals named are quite like those of the plagioclase-bearing basalts. No feldspar has been noted. The rock is thus clearly the nonfeldspathic extreme of the basaltic series of Kauai.

Added interest attaches to this rock from the numerous sharply angular inclusions of dunite and harzburgite contained in it. They range in the specimens collected from fragments 4 centimeters in diameter to minute grains. These xenoliths are granular in texture, are green or gray in color, and consist almost entirely of fresh olivine and pyroxenes, and of the latter enstatite is the most abundant variety. Some fragments are nearly pure olivine. Iron oxide particles are rare and no feldspar, biotite, or hornblende has been detected.

[1] Am. Jour. Sci., 4th ser., vol. 29, p. 59, 1910.

This limburgite magma has thus brought up from some depth granular rocks of even simpler composition than its own. No other kinds of rocks were observed as inclusions in the limburgite. Similar xenoliths are present in certain basalts of Oahu, Molokai, and Hawaii, mentioned later.

Limburgite was also found with common basalts among bowlders of the bed of Waimea River above the mouth of Waialae River.

OLIGOCLASE GABBRO, OR KAUAIITE.

Occurrence.—In reporting the discovery of a coarsely granular rock, called "olivine diabase," in the west fork of Wailau Canyon, on the island of Molokai, Lindgren [1] states that a piece of very similar rock was given to him with the assurance that it had been "broken from a large bowlder in one of the principal streams on Kauai." Through information given to me by Judge Hardy, of Lihue, and Mr. Francis Gay, of Kekupua, I found what I believe to be the bowlder from which the granular rock given to Mr. Lindgren was obtained. In the deep canyon of Waialae River, an eastern branch of the Waimea Canyon, there is a bowlder 12 feet long and 6 to 8 feet high and wide, known to the natives, according to Mr. Gay, as "the lightning stone." It is composed of rock like the specimen given to Mr. Lindgren, which I have examined.

The exact source of this granular rock is unknown. From commanding positions on the ridge south of the canyon where the fragments occur no outcrops suggestive of a core were seen, but the jungle of tropical vegetation covering many of the slopes might well conceal a large body. The bowlders of granular rock occur in the stream bed below the "lightning stone" for about a quarter of a mile, to the junction with the main Waimea, and are also found in the detritus of the Waimea above the forks, although no fragment so coarse grained as the rock to be described was noted. For perhaps 100 yards above the "lightning stone" there are a few fragments in the stream gravels, but for several hundred yards still farther upstream no pebbles or bowlders of this granular rock were found. It thus seems likely that the ridge between the main Waimea and the Waialae contains a mass of the peculiar gabbroic rock here discussed.

The repeated statements of natives to Mr. Gay, that this particular bowlder is often struck by lightning, is not borne out by fulgurites or other evidence noted. The upper part of the mass has a dark crust of weathering. On the sides it is gray in color and there are many round pits, an inch or two across and an inch deep, irregularly scattered over the surface. These pits resemble the beginning of drill holes, but they are believed to result from weathering action about miarolitic cavities.

Description.—The size and shape of the large bowlder made it impossible to obtain a hand specimen of it, but smaller ones near by afforded better opportunity. The specimen of which a chemical analysis was made is a granular porous rock (see Pl. II, *B*) of dark-gray color, exhibiting many irregularly disposed augite prisms somewhat less than 1 centimeter long and 3 millimeters thick. It contains many tablets of plagioclase, some nearly 1 centimeter in length, and still more abundant is a finer-grained pinkish-gray feldspathic mass in which augite and the larger crystals of plagioclase are embedded. Scattered through the mass are many irregular miarolitic cavities, of various sizes up to 1 centimeter or more. Crystals of augite, plagioclase, orthoclase, apatite, and magnetite project into these cavities, and some of the crystals show well-developed crystal planes.

W. T. Schaller [2] has described crystals of orthoclase, apatite, and titaniferous augite found in these cavities. The augite exhibited eight determinable forms, two of which, belonging to the prismatic zone, are new.

The microscopic texture is irregularly granular. Small laths of calcic labradorite or bytownite penetrate both augite and olivine but are not abundant. The average or normative plagioclase, assuming all albite combined with anorthite and orthoclase as albite-free, is about Ab_3An_1. As developed in the rock there is perhaps the normative amount of orthoclase, namely, about 8 per cent. The dominant feldspar is plagioclase, most of the individuals of which have inner bands of labradorite and outer zones of highly sodic feldspar, probably anorthoclase. The

[1] U. S. Geol. Survey Water-Supply Paper 77, p. 15, 1903.

[2] U. S. Geol. Survey Bull. 509, pp. 85–87, 1912.

labradorite portion is broader than the laths penetrating augite and exhibits albite, Carlsbad, and pericline twinning, the last very subordinate. The albite and Carlsbad twins indicate a highly calcic labradorite.

The zones of differing composition are commonly not symmetrically developed about a center, but consist of bands parallel to (010), and the gradation from labradorite to alkalic feldspar with index of refraction lower than balsam is rapid. Definite andesine and oligoclase bands have not been determined. Albite-twinning lamellæ are visible in the outer zones in places, but are not characteristic, while a mottled shadowy extinction is common. This sodic feldspar interlocks irregularly with other components.

The norm of this rock shows a little nephelite, but none has been found in the specimen analyzed, either microscopically or by chemical test. Sections of the coarser-grained "lightning stone" bowlder show crystals of apparent nephelite in small amount.

Olivine of a pale-yellowish tinge is present in a few crystals. The prominent augite has a pink or violet color, which testifies to its contents in titanic oxide. On borders it often exhibits ægirite-augite and in places distinct ægirite of strong green color, normal pleochroism, and orientation. Crystals projecting into cavities or interlocking with alkali feldspars most commonly exhibit this gradation to ægirite.

Apatite, characterized by dustlike inclusions, is unusually abundant in large prisms. The norm shows that 5.0 per cent is present. Titanomagnetite is also a prominent constituent, the character being indicated by opaque rims of leucoxene about many crystals.

Chemical composition.—The moderately coarse grained rock to which the above description particularly applies and which is represented by Plate II, *B*, was analyzed by W. T. Schaller with the result given below. The notable features are low alumina, high lime, preponderance of soda over potash, and high phosphoric acid and titanium oxide. The influence of the chemical composition on the modal character of the rock is best shown by the calculation of the norm.

Analysis and norm of kauaiite.

Analysis.	26	Mol.
SiO_2	45.81	763
Al_2O_3	11.90	117
Fe_2O_3	4.62	29
FeO	8.09	112
MgO	5.39	135
CaO	10.67	190
Na_2O	4.28	69
K_2O	1.40	15
H_2O-	.47	
H_2O+	.53	
TiO_2 [1]	4.05	50
P_2O_5	2.20	15
S	.03	
MnO	.17	2
BaO	.04	
SrO	Trace.	
	99.65	

Norm.	
Orthoclase	8.34
Albite	29.34
Anorthite	9.17
Nephelite	3.69
Diopside	23.81
Olivine	4.82
Magnetite	6.73
Ilmenite	7.60
Apatite	5.04
	98.54
Rest	1.07
	99.61

Quantitative classification.—Normative ratios showing the position of the rock in the quantitative system are as follows:

Class: $\frac{Sal}{Fem}=\frac{50.54}{48.00}=1.05=III$, salfemane.

Order: $\frac{L}{F}=\frac{3.69}{46.85}=0.08=5$, gallare.

Rang: $\frac{K_2O'+Na_2O'}{CaO'}=\frac{84}{33}=2.55=2$, kilauase.

Subrang: $\frac{K_2O'}{Na_2O'}=\frac{15}{69}=0.22=4'$, kilauose.

Symbol: III.5′.2.4′.

[1] It is thought by Mr. Schaller that Ti_2O_3 may be present in small amount. ZrO_2, CO_2, Cr_2O_3, and Li_2O were sought for but not detected.

The low alumina content of this rock, in conjunction with rather high alkalies, brings it well within the domalkalic rang of the perfelic salfemanes. Clearly the lime must largely go to the augite.

Systematic relations and name kauaiite.—This sodic gabbro is most nearly related to the lavas of Kilauea among Hawaiian rocks. The basalts of the Olokele Canyon rim are far less alkalic in their feldspathic contents. The subrang kilauose is represented by few analyzed rocks, as a glance at Washington's Tables will show. Division VII of the table on page 70 gives analyses of the few close analogues found for this rock and the nearest allied lavas of Kilauea.

The rarity of analogous granular rocks shows that the Kauai type is not adequately characterized by calling it gabbro or augite diorite. With my concurrence, J. P. Iddings [1] has applied the name kauaiite to "oligoclase-augite diorites" richer in salic constituents than the commoner andesine-bearing augite diorites, having reference to this rock as a chemical representative. Manifestly the magmas of this composition may vary considerably as to the composition of their plagioclase, one phase being the labradorite-anorthoclase development of the rock of Kauai.

MELILITE-NEPHELITE BASALT.

Occurrence.—Adjacent to the landing place for interisland boats on the north shore of Kilauea Bay, in northern Kauai, are ledges of black basalt overlain by tuffs. The basalt is rich in augite, olivine, nephelite, melilite, and magnetite and is best named melilite-nephelite basalt. On several accounts this rock deserves description, although the material at hand is scanty.

This basalt was observed only at and near the Kilauea Bay landing. It there forms a ledge a few yards thick, so far as noted. The overlying stratified basaltic tuffs form the principal part of a narrow headland separating Kilauea Bay from a nearly semicircular bay on the north, which is believed to occupy a portion of the crater of one of the numerous recent explosive vents that abound on Kauai. Bedded tuffs dipping south, west, or northwest from a point in the bay seem to indicate the position and size of the crater, more than half of which has been cut away, apparently by marine erosion. It is deemed probable that the flow of Kilauea Bay came from this center, but no specimens of the tuff were collected by which this relation might have been established.

Description.—The rock is dark gray and almost aphanitic, the only prominent element being white zeolitic aggregates filling minute pores. Examination with a hand lens reveals small crystals of olivine and suggests the actual holocrystalline character of the mass.

In thin sections olivine, augite, melilite, nephelite, and magnetite are found to be abundant constituents, in the order named. Apatite is also abundant and minute biotite flakes occur sparingly. All these minerals are nearly fresh and possess the characters common to them in basaltic rocks.

A rude microporphyritic texture is given to the rock by the size of some of the olivine crystals, but this texture is obscured by the serial gradation from the larger crystals to the smaller grains corresponding in size to those of the other constituents. The large olivines measure 1.5 millimeters in length and are more perfectly developed crystals than the smaller ones.

Melilite is next to olivine in size. It occurs in fresh tablets, the largest being 1 millimeter wide and 0.2 millimeter thick. The basal planes are not present and the crystals tend to the rude biconcave form characteristic of the mineral. Augite, magnetite, and nephelite penetrate the melilite substance. Cleavage parallel to the base is broken by many vertical partings. "Peg structure" is shown only in rudimentary form in a few crystals.

There is no glassy base. The original pores of the rock, of irregular shape, are surrounded by fresh crystals of nephelite, augite, magnetite, and apatite. The fine radiate, fibrous, zeolitic filling does not appear to be a product of decomposition of the surrounding rock.

Chemical composition.—An analysis of the rock by W. F. Hillebrand is given under No. 43 of the table on page 17. Under No. 43a is shown the analysis of that part of the rock soluble in dilute nitric acid (1:40).

[1] Igneous rocks, pt. 2, p. 173, 1913.

Analyses and norm of melilite-nephelite basalt.

Analyses.			Norm.	
	43	43a		43
SiO_2	37.50	15.84	Leucite	2.62
Al_2O_3	9.12	7.68	Nephelite	12.21
Fe_2O_3	5.59	1.47	Anorthite	11.12
FeO	8.81	.47	Diopside	31.04
MgO	13.72	3.39	Olivine	18.56
CaO	13.85	5.21	Akermanite	3.92
Na_2O	2.69	2.28	Magnetite	8.12
K_2O	.63	.60	Ilmenite	6.08
H_2O-	1.05	1.05	Apatite	2.12
H_2O+	2.35	2.35	Calcite	.60
TiO_2	3.21	.05		
ZrO_2	.02	.....		96.39
CO_2	.27	.27	Rest	3.68
P_2O_5	.90	.90		
Cl	.05	.03		99.97
S	Trace.	.....		
Cr_2O_3	.07	.....		
V_2O_3	.05	.....		
NiO	.04	.....		
MnO	.15	.....		
BaO	.07	.....		
SrO	.05	.....		
	100.19	41.59		

As shown in Division XIV of the table on page 77 this rock is similar in chemical composition to other melilite-bearing basalts of Texas, Baden, and Bavaria.

Quantitative classification.—The position of this rock in the quantitative system is shown by the ratios given below:

Class: $\frac{Sal}{Fem}=\frac{25.9}{69.9}=0.37=IV$, dofemane.

Order: $\frac{PO}{M}=\frac{53.7}{14.2}=3.77=2$, scotare.

Suborder: $\frac{P}{O}=\frac{29.9}{23.8}=1.38='3$, texiare.

Symbol: IV.2.'3.2.2.

Rang: $\frac{MgO+FeO}{CaO''}=\frac{500}{202}=2.31=2$, uvaldase.

Subrang: $\frac{MgO}{FeO}=\frac{343}{157}=2.77=2$, uvaldose.

BASALTS DESCRIBED BY MÖHLE.

The Schauinsland collection contains but three rocks from Kauai, and these are olivine-plagioclase basalt, rich in olivine, from a locality given by Möhle [1] as Tipukai, which may refer to an area called Kipukai, 3 or 4 miles southwest of Nawiliwili Bay.

ISLAND OF OAHU.

INTRODUCTORY NOTE.

The island of Oahu, upon which Honolulu is situated, embraces about 600 square miles. It lies about 70 miles southeast of Kauai and is the next younger island according to one idea of the history of the Hawaiian group. Oahu is a volcanic doublet, exhibiting two main centers of eruption, represented now by two mountain ranges rather than by forms referable to great

[1] Neues Jahrb., Beilage Band 15, p. 90, 1902.

craters. The western range is called the Kaala and the eastern the Koolau, and each exhibits a great amount of denudation. The structure of each range is well shown in cliffs and gorges.

In Oahu, as in Kauai, the sculpturing of the older volcanic piles into mountains of about the present character was followed by a renewal of volcanic activity, resulting in many relatively small cinder cones and lava flows. Some of these, like the Punch Bowl and Diamond Head tuff cones, near Honolulu, are so little modified by erosion that they must be considered as very recent.

Although many geologists have visited Oahu, but few of its lavas have been closely studied and identified. In 1889 E. S. Dana[1] gave petrographic descriptions of 12 massive lavas of Oahu. Most if not all of these came from the older eruptions of the island, and all are basalt, but they have variable olivine content, and Dana remarked as to a few specimens that "their highly feldspathic character and the microscopic structure made it seem as if they might more properly belong to the andesites."

In 1896 A. B. Lyons[2] published analyses and brief descriptions of four rocks of Oahu, referring to them as basaltic lavas, but commenting on the abundance of feldspar in one of them.

The discovery of a nephelite-melilite basalt near Honolulu was announced by G. P. Merrill[3] in 1900. This rock is described on pages 20–22.

These three publications embrace all the earlier definite determinations of the lavas of Oahu from known localities. C. H. Hitchcock,[4] in describing the geology of the island, calls the rocks basalts, with special reference to the prominent olivine in some of them. Other writers have been equally general and it seems to have been commonly assumed that nearly all the lavas must be of normal basaltic character.

In 1899 Hitchcock made a collection of the lavas of Oahu for the National Museum, and among them was the nephelite-melilite basalt described by Merrill. Knowing of this collection I made little attempt to obtain further material from Oahu. Having been unable through pressure of other work to complete his petrographic study of the Hitchcock collection, Dr. Merrill has very generously placed these specimens, with thin sections, at my disposal, and they form the basis for the greater part of the discussion which is to follow concerning Oahu.

Prof. Hitchcock has supplemented the collection just mentioned by additional material gathered while this study was in progress, partly in response to my requests. I am therefore under direct obligation to him for material and information of much value.

RANGE OF LAVAS.

The known lavas of Oahu are perhaps all referable to the great basaltic group, but they exhibit notable varieties expressed by the following terms: Olivine-plagioclase basalt, bronzite basalt, plagioclase basalt (olivine free), nephelite basalt, nephelite-melilite basalt, tephrite, limburgite, and gabbro. All these varieties, except the last, express notable chemical differences in the magmas.

OLIVINE-PLAGIOCLASE BASALT.

Basalts in which plagioclase, olivine, augite, and titaniferous magnetite are the only prominent minerals are not abundant in the Hitchcock collection. Twenty specimens may be thus described and they fall into three rather distinct groups. Most of them are normal in that all the silicates named are abundant, though in varying proportions. The small amount of plagioclase in three rocks produces a more basic type than the normal, and a marked decrease in olivine makes a third variety. Magnetite is not abundant in any of these lavas, and in some of them the amount is very small. Naturally the basalts exhibit many textural phases, as is usual in such rocks.

The normal basalts are widely distributed. Only two of them come from the Koolau Range, and these occur at the southeast extremity, one in the tract called Niu, northwest of the cinder cone Koko Head, and the other in a spur of the range northeast of the cone.

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[1] Am. Jour. Sci., 3d ser., vol. 37, pp. 466–467, 1889.
[2] Idem, 4th ser., vol. 2, p. 424, 1896.
[3] Am. Geologist, vol. 25, p. 312, 1900.
[4] Geol. Soc. America Bull., vol. 11, pp. 15–60, 1900.

Five specimens come from the Kaala Range, but only two of these belong surely to flows, one in the Makua Cliffs and the other at the extreme north end of the range. The groundmass of the latter rock contains a notable amount of biotite—a rare mineral in Hawaiian rocks. A specimen from the watershed ridge west of the military reservation has an unusual texture. It is rich in labradorite (Ab_3An_7) tablets 0.5 centimeter long and has an ophitic groundmass with interstitial glass. It is also vesicular and resembles the rock near Hilo described farther on. The mode of occurrence is not stated. The other two rocks of this group occur as dikes, at Kaena Point and in Makua Cliffs, respectively. The former is so nearly granular that it may well be termed olivine diabase, the augite being developed in grains inclosing plagioclase.

Two typical basalts occur in low exposures north of Pearl Harbor—at Eva Church and on the east line of the Eva plantation, on the Government road. Possibly these belong to old flows of the Kaala center, but the fact that normal basalt occurs in the Kuna cone, at the south end of the Kaala Range, one of the recent group called by Hitchcock[1] the "Laeloa craters," seems to indicate a possible recent age for the lowland rocks mentioned.

The recent center of eruption in the low country east of Honolulu, called Kaimuki or Telegraph Hill, is characterized by normal basalt represented by four specimens in the Hitchcock collection. Maumae, a crater cone lying a little north of Kaimuki, is likewise a center of recent eruption of normal basalt.

Two specimens of common basalt from East Koko Head, a tuff cone at the extreme southeast point of Oahu, may represent the lavas of the Koolau series of flows, as Hitchcock states that these older rocks are exposed beneath the tuffs of the cone.

The feldspathic basalt poor in olivine came from a quarry at the east end of Judd Street, at the south extremity of the spur between Pauoa and Nuuanu valleys, Honolulu. It is a minutely vesicular rock from a flow of the pahoehoe type and may belong to the Koolau flows.

The basalts poor in plagioclase but rich in olivine and augite come from recent eruptions east of Honolulu. One of them occurs as a dike in the tuffs of Diamond Head and the other represents a recent lava flow at the point called Kupikipikio, just east of Diamond Head.

BRONZITE-BEARING BASALT.

Basalts of the usual habit and composition, except that olivine is to some extent replaced by a rhombic pyroxene, are widely distributed in Oahu. The relative proportions of olivine and bronzite—as the pyroxene may best be called—differ greatly in the rocks examined. Some are rich in both minerals, others carry both in small amount, in some olivine strongly predominates, and in others bronzite appears to the exclusion of olivine.

The rhombic pyroxene is often colorless, with faint pleochroism, and must be less rich in iron than hypersthene. It occurs only in prismatic phenocrysts, so far as observed, and plays throughout a rôle like that of olivine.

These rocks are apparently more abundant than the normal basalts in the Koolau Range. Sixteen specimens in the original Hitchcock collection come from the following localities in that range: (1) Niu, near Koko Head, (2) Manoa Valley, (3) Kalihi valleys, (4) east base of Tantalus, (5) spur between Manoa and Nuuanu valleys (several specimens), (6) the Pali, (7) Waialua Plain, (8) Waimea Gulch, on railroad, (9) cliffs back of Kahuku plantation, (10) cliff at Laie Point. These localities are distributed from the southeast to the northwest extremity of the range.

The later collection made by Hitchcock shows that bronzite-bearing basalts are common near Honolulu. Several specimens were obtained near the polo grounds, in Moanalua.

From the Kaala Range but three specimens were obtained—one from a dike in the Makua Cliffs, one from Kaena Point, where it is cut by the dike of ophitic texture above referred to, and one from the highest point in the valley between the Kaala and Koolau ranges, nearer to the Kaala.

The other bronzite basalts occur as fragments in the tuffs of Makalapa and Oliamanu, two of the recent cinder cones near Pearl Harbor. They probably represent old lavas of

[1] Geol. Soc. America Bull., vol. 11, p. 36, 1900.

the Koolau Volcano. It is noteworthy that this rock was not found among the products of recent eruptions near Honolulu.

The Dana collection embraces 12 basalts of Oahu, and all belong apparently to the lavas of the older centers. In 11 of these rocks an almost colorless rhombic pyroxene occurs in variable amount. These rocks came from Moanalua, Punaluu, Kahuku, and the Waialua Plain, the first three localities belonging to the Koolau center, while the last is between the two mountain ranges of the island. Dana [1] specially refers to two highly chrysophyric rocks, and these serve admirably to illustrate the variations in composition and possibly the genetic relations of several phases of these lavas.

A chrysophyre of Kahuku Head contains an extraordinary amount of olivine in prominent phenocrysts. Dana estimates the olivine as probably two-thirds of the mass. Nearly all the phenocrysts are olivine, with rare comparable ones of bronzite. The groundmass is in its composition and texture nearly a counterpart of many of the finer-grained lavas of Oahu, which contain microphenocrysts of bronzite in a mass of augite, plagioclase, and magnetite. Olivine is rare or lacking in the latter rocks and, as Dana pointed out, they approach pyroxene andesites very closely in composition.

A rock of Waialua Plain contains augite and bronzite associated with the dominant olivine phenocrysts and also some corresponding labradorite crystals. The groundmass is here also similar to some of the olivine-poor lavas.

In general these olivine-poor bronzite basalts of Oahu seem similar in composition to the Mesozoic olivine weisselbergite of Rosenbusch [2] where bronzite and olivine play the same rôle, replacing each other with slight differences in chemical composition of the rock, especially as to silica. Weisselbergite is classed by Rosenbusch with the andesites (augite porphyrites).

PLAGIOCLASE BASALT (OLIVINE-FREE).

Several basalts of the Hitchcock collection consist almost wholly of augite, labradorite, magnetite, and a small amount of apatite. Olivine is rare or absent. These rocks are aphanitic and contain no notable phenocrysts of any kind. In both composition and texture they correspond to the groundmass portion of some of the normal basalts. Labradorite is older than the augite, which occurs in small grains between the feldspars and not in large chadocrysts inclosing them. No doubt the rocks of this group exhibit in some occurrences a development of augite and labradorite phenocrysts and other textural variations not shown in the specimens at hand.

Nine specimens belonging to this group have been examined. Four of them occur at the Pali gap in the Koolau Range. Two at least occur as dikes; the others are not specified as to whether flows or dikes. It is a natural suggestion that these rocks belong not to the older series of Koolau lavas but to the comparatively recent eruptions of this locality noted both by Hitchcock and by me.

Four other rocks free from or very poor in olivine occur in ledges on the Oahu plantation, in the broad, low valley between the Kaala and Koolau ranges and 2 or 3 miles north of the recent vents adjacent to Pearl Harbor. Presumably these rocks are exposed in the walls of channels cut through the soil, etc., by streams from the Koolau Range, but the source of the lavas may not be determinable. In all these rocks an insignificant amount of olivine or bronzite, or both, occurs in very small phenocrysts or in anhedra like those of augite.

NEPHELITE-MELILITE BASALT.

Occurrence.—The existence of the nephelite and melilite bearing basalt of Oahu was first announced by Wichmann [3] in 1875 on examination of ballast rock brought by a ship to Hamburg. The source of the material was said to be Oahu, but the exact locality was not known. Cohen [4] later studied some of these ballast fragments and confirmed Wichmann's statements as to

[1] Am. Jour. Sci., 3d ser., vol. 37, p. 466, 1889.
[2] Mikroskopische Physiographie der massigen Gesteine, 4th ed., p. 1094, 1908.
[3] Neues Jahrb., 1875, p. 172.
[4] Idem, 1880, vol. 2, pp. 23–62.

nephelite and melilite, and Stelzner [1] completed the identification of the melilite. Möhle [2] refers to a melilite-nephelite basalt from the vicinity of Honolulu.

The rock collected by Hitchcock and described by Merrill [3] in 1900 appears to be the first nephelite-melilite basalt from Oahu of which the occurrence is known. I visited the locality from which the rock described by Merrill was obtained. It is so unusual a type as to warrant further microscopical and chemical study and description.

The Schauinsland collection described by Möhle contained one specimen of nephelite-melilite basalt from Oahu, but as the locality is indefinite, being "aus der Umgebung von Honolulu," it is uncertain whether this rock belongs with one of the occurrences to be described or not.

The rock described by Merrill as "nepheline-melilite basalt" and further discussed below occurs in a quarry near Moiliili Church, about midway between Punch Bowl and Diamond Head, in the eastern suburbs of Honolulu. The small outcrops are surrounded by alluvium, and the source of the lava stream which the rock represents is not definitely known. Hitchcock [4] says of this occurrence:

> It is surmised that this rock came from Rocky Hill, as there is a slope from the crater to the quarry and to the church. There are several masses of cinders interrupting the continuity of the basalt, which are suggestive of blowholes and steam vents. Amygdaloidal and zeolitic minerals occur at the quarry. Phacolite and laumontite have been identified among them. Calcite and amorphous silica are also present, the latter on surfaces several square feet in extent in rudely parallel lines. The bluff is traversed by small veins full of nephelite, granular melilite, and augite. Either of these minerals may form a layer of crystals, closely crowded together, all standing vertically to the plane of occurrence. Veins 3 inches wide or less abound in these minerals, mixed with a multitude of acicular crystals of kaliophilite. Mr. Wirt Tassin has identified these species.

In the Hitchcock collection there are many specimens from the Moiliili quarry and also of similar rock from the following localities: (1) At and near Rocky Hill, Manoa Valley, (2) Kalihi Valley, north edge, (3) Gulick Stream, west of Kamehameha School, Honolulu, (4) half a mile east of Bishop Museum.

Rock from quarry near Moiliili Church.—The specimens from the quarry near Moiliili Church exhibit some textural differences, but on the whole a marked uniformity. I will first describe the type analyzed, collected by me.

This rock is megascopically a gray massive trap of millimeter grain, the holocrystalline character of which is suggested by numerous glistening crystal or cleavage faces of unrecognizable minerals. The hand lens reveals a large amount of light-colored minerals. No phenocrysts can be observed. There are some small irregular cavities lined with a thin zeolitic crust. The constituents are olivine, augite, melilite, nephelite, magnetite, and apatite, all but the apatite being abundant. All the minerals are very fresh, and the absence of iron hydroxide and other stains makes recognition of almost every particle possible.

Olivine occurs in colorless, nearly euhedral prismatic crystals reaching a maximum size of 1.5 millimeters. It is nearly free from inclusions, and much of it exhibits no alteration. It seems to form about one-fifth of the rock, as found also in the norm.

Augite is less abundant than olivine and less prominent, for it occurs in anhedrons interlocking most irregularly with other minerals and in some places being the oikocryst or matrix crystal of the poikilitic fabric. Its major diameter seldom exceeds 0.6 millimeter. The augite has the reddish or yellowish-brown pleochroic colors of titaniferous varieties but not very strongly.

Melilite appears in the usual basal tablets, presenting most commonly long rectangular outlines. The prism faces are much sharper than the basal, interlocking with nephelite and magnetite in particular being common on the basal sides. The melilite is fresh, without "peg structure" in the rock analyzed, has a few marked basal cleavage planes, and seldom contains inclusions. It is colorless and of pale-bluish or milky polarization color in thin sections. The substance of last deposition in the outer basal zones, between particles of other minerals, is

[1] Neues Jahrb., 1882, vol. 1, p. 229.
[2] Idem, Beilage Band 15, p. 83, 1902.
[3] Am. Geologist, vol. 25, pp. 312-313, 1900.
[4] Geol. Soc. America Bull., vol. 11, pp. 46, 47, 1900.

often of higher double refringence than the central zone, appearing yellowish in polarized light. The melilite forms about 15 per cent of the rock.

Nephelite is developed in very sharply defined euhedral or subhedral grains, few of which exceed 0.1 millimeter in diameter in the rock analyzed. It includes magnetite and apatite especially but is penetrated by all other minerals. It is fresh and has a very slightly higher refractive index than Canada balsam. It forms nearly or quite one-quarter of the rock.

Magnetite occurs abundantly in subhedral crystals and groups, nearly as large as the nephelite. It gives no special indication of titanium content, but a test of powder separable with the magnet gave 13.4 per cent TiO_2. No perofskite was noted, but Merrill reports that mineral as present. Apatite is developed in minute long prisms.

A photomicrograph of this rock is given in Plate III, *B*.

The Hitchcock collection shows that the rock of the Moiliili quarry varies little in composition and texture. Olivine has less tendency to phenocrystic development in some specimens. Augite often appears more markedly as an irregular oikocryst, inclosing nephelite and magnetite, but in some of the rock it is found only in small roundish grains. In the coarsest-grained specimens nephelite and a part of the magnetite reach a diameter of 1 millimeter and the texture is nearly equigranular.

The analysis, by George Steiger, and the calculated norm of this rock are given below:

Analysis and norm of nephelite-melilite basalt.

Analysis.	40	Mol.	Norm.	
SiO_2	36.34	606	Leucite	8.28
Al_2O_3	10.14	99	Nephelite	21.02
Fe_2O_3	6.53	41	Anorthite	1.67
FeO	10.66	148	Diopside	17.39
MgO	10.68	267	Olivine	20.23
CaO	13.10	234	Akermanite	11.95
Na_2O	4.54	74	Magnetite	9.51
K_2O	1.78	19	Ilmenite	5.47
H_2O-	1.00		Apatite	2.35
H_2O+	1.00			97.87
TiO_2	2.87	36	H_2O	2.00
CO_2	.15	3	Calcite	.31
P_2O_5	1.02	7		100.18
S	.04			
MnO	.20	3		
	100.05			

Quantitative classification.—The position of this rock in the quantitative system is shown by the ratios given below:

Class: $\frac{Sal}{Fem}=\frac{30.97}{66.90}=0.46=$'IV, dofemane.

Order: $\frac{P+O}{M}=\frac{49.57}{14.98}=3.10=2$, scotare.

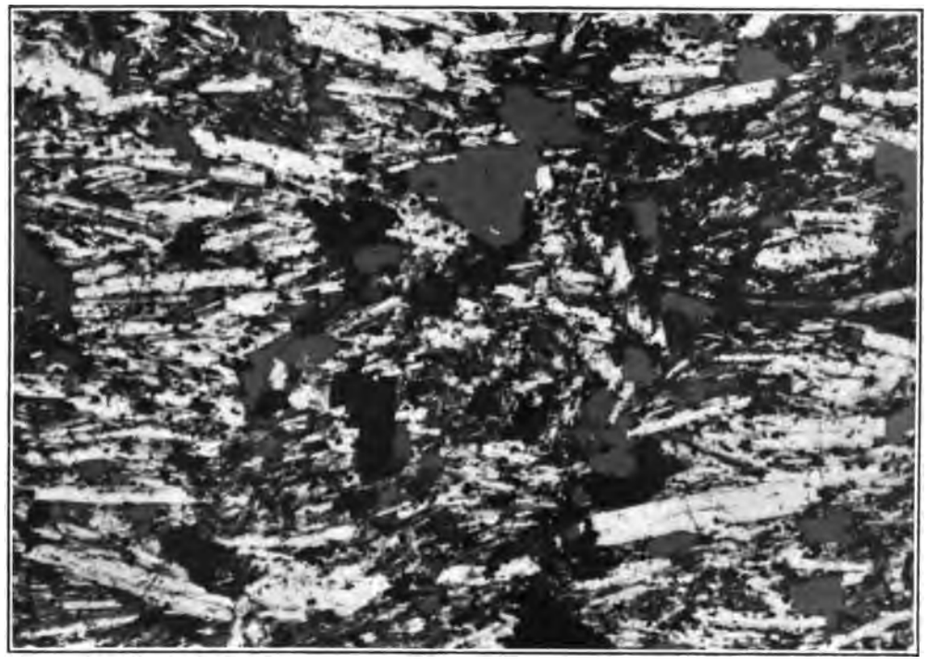
Section: $\frac{P}{O}=\frac{17.39}{32.18}=0.54=(3)4$ (unnamed).

Rang: $\frac{(FeMg)O}{6aO''}=\frac{418}{225}=1.86=2(3)$, casselase.

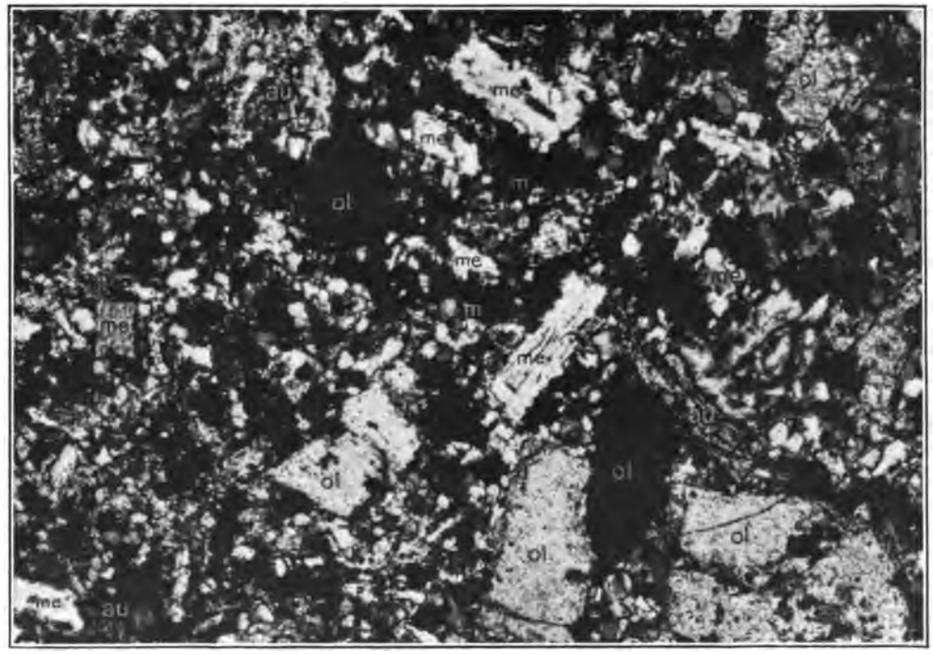
Subrang: $\frac{MgO}{FeO}=\frac{267}{151}=1.77=2(3)$, casselose.

Symbol: 'IV.2.$_{(3)}$4.2(3).2(3).

The rock thus falls in casselose but is transitional in several respects. The rang and subrang to which it is transitional are unnamed as yet, but through its near approach to section 3 of order 2, texiare, it becomes also transitional to uvaldose, a subrang containing the nephelite-melilite basalt of Kauai and the picritic basalt of Haleakala. The relation of this rock to other melilite basalts is brought out in Division XII of the table on page 75. It is certainly significant that the "black sand" or ash, so abundant about Honolulu, has a marked resemblance to this basalt of the Moiliili quarry in composition, as is also illustrated in Division XII.



A. SODA TRACHYTE, LAUNIUPOKO HILL, NEAR LAHAINA, MAUI.



B. NEPHELITE-MELILITE BASALT, NEAR HONOLULU, OAHU.

au = augite, m = magnetite, me = melilite, ol = olivine.

PHOTOMICROGRAPHS OF HAWAIIAN ROCKS.

NEPHELITE BASALT AND ALLIED ROCKS.

In the Hitchcock collection are several rocks which in the current nomenclature must be called nephelite basalts, although this name unduly emphasizes a very subordinate constituent. It is probable, I think, that these lavas, like the melilite-bearing and other extreme types, are of recent origin and local occurrence, but so little is known of the actual field occurrence and relations of these rather obscure rocks that extended description is scarcely desirable at present.

In general, these rocks are rich in augite, olivine, and magnetite. They are all aphanitic, and as a rule olivine is the only phenocryst. The dominant and often obscure mass of augite and magnetite is very fine grained and in some places there is a small amount of residual glass. Olivine probably takes some part in this almost unresolvable mixture.

The nephelite occurs in mostly anhedral specks penetrated by augite and magnetite. Its habit is the same as in the finer grained of the melilite basalts and identification rests on this fact, with the close agreement of its index of refraction with that of balsam and the weak birefringence. In one specimen an alkali-rich feldspar is associated with the nephelite in small amount.

Among the localities for nephelite basalt is the Punch Bowl, near Honolulu—probably from a dike; another is Kapuai, one of the Laeloa craters;[1] a third is one of the Salt Lake craters; and a fourth is a dike in the Pali, 750 feet below the road pass, on the east side. Möhle[2] found a nephelite basalt in the Schauinsland collection, from some locality near Honolulu.

Allied rocks which may be called nephelite basanite occur at Diamond Head (dike?) and Kapolei, a crater of the Laeloa group. The specimens representing them are very dense basic rocks deserving further study on better material.

The rock of one of the dikes in the Pali, near the road, is perhaps best named a limburgite.

BASALTIC TUFFS AND ASHES OF RECENT ERUPTIONS.

From a review of all available data it appears that most if not all of the tuff cones and craters of comparatively recent age on Oahu represent eruptions of lavas more basic than normal basalt. The melilite and nephelite bearing rocks and other varieties described above seem the common products of these centers.

The tuffs themselves have seldom been described. In the Schauinsland collection Möhle[3] found palagonite tuff from the Punch Bowl and more normal basaltic tuff from the vicinity of Pearl Harbor and from the Salt Lake craters. Lyons[4] has analyzed several lime and magnesia rich hydrated tuffs of Punch Bowl, Diamond Head, and other localities.

Hitchcock[5] has given valuable data concerning the general character of many of these recent centers of eruption near Honolulu, under the heading "Secondary craters," but without petrographic determinations. Although the Hitchcock collection contains many specimens of tuff and fragments, most of them are much altered or otherwise unsuited to be taken as representative of the cones from which they came. The petrographic nature of the eruptions from a given center can be satisfactorily determined only by careful field studies made by a petrographer.

The occurrence of the peculiar "black ash," a volcanic sand of notable homogeneity forming a deposit over a large area about Honolulu, has been examined by Hitchcock[6] with much care. His conclusion is that it originated in Punch Bowl, Tantalus, and a third crater. Lyons's analysis of the ash[7] bears so close a resemblance to that of the nephelite-melilite basalt of the Moiliili quarry that I have included it in the collection of igneous-rock analyses (No. 37, p. 48), believing that it represents a particular magma. It seems possible that this ash and the Moiliili flow of basalt came from the same center, or at least that they are contemporaneous eruptions.

It is noteworthy that these two rocks contain much more potash than the other basic rocks of the islands, and it is reported by chemists of the agricultural experiment station near

[1] Hitchcock, C. H., Geol. Soc. America Bull., vol. 11, p. 37, 1900.
[2] Neues Jahrb., Beilage Band 15, p. 83, 1902.
[3] Idem, p. 85.
[4] Am. Jour. Sci., 4th ser., vol. 2, p. 427, 1896.
[5] Op. cit., pp. 36–52.
[6] Idem, p. 49.
[7] Op. cit., p. 424.

Honolulu that much of the volcanic ash in the lowlands of Oahu is rich in potash. In fact, a Honolulu newspaper quotes E. V. Wilcox, of the experiment station laboratory, as saying that some ashes analyzed have 7 per cent of potash.

From a petrographer's standpoint it would be singular to find an ash anywhere in Hawaii which is richer in potash than in soda. But the rocks just mentioned show such unusual richness in potash that the possibility of still richer ones must be acknowledged. If highly potassic tuffs or ash beds occur in the islands it is to be hoped that their petrographic relations may be determined and their source established.

ISLAND OF MOLOKAI.

ROCKS DESCRIBED BY MÖHLE.

The principal contribution to the petrography of Molokai is the description by F. Möhle[1] of about 50 specimens of massive rock collected by Schauinsland. These specimens are said by Möhle to come from points scattered all over the island, but he gives details of locality for only a few of them. A large part of the material came from the Pali, a cliff facing the leper settlement on the north coast, and represents lavas of the great eastern volcanic center, which Dana[2] regarded as having been divided by a fault running near the north coast, the Pali being considered as practically a fault scarp.

The lavas of Molokai are said by Möhle to be of typical basaltic character, consisting of plagioclase, augite, olivine, and magnetite, but there is much variation in the quantitative relations of these constituents and he accordingly distinguishes three groups, which are connected by intermediate rocks. First and most abundant are types characterized as normal olivine-bearing basalts, with the qualification that the olivine content is not high; second come rocks in which olivine is rare or, in six specimens, entirely lacking; third, and contrasting with the second group, there are rocks in which olivine is abundant and augite rare or lacking.

The so-called normal basalts are generally porphyritic, with tabular phenocrysts of labradorite and prisms of augite or rhombic pyroxene, the latter in two rocks only. Olivine appears to be decidedly subordinate for a normal basalt, and in his conclusion that these rocks are basalts rather than andesites Möhle seems to be influenced mainly by the silica contents, which he found in three lavas to be 48.21, 46.47, and 45.11 per cent.

The augite-free basalts are said to have an abundant colorless glass base, and biotite occurs in one of them. They are compared to lavas from Hawaii described by Cohen, to which reference will be made.

An aphanitic aphyric rock from Kalae is called "Nephelinbasanitoid" by Möhle. Besides predominant feldspar, augite, olivine, and magnetite, there are a few crystals of nephelite in this rock. Tests with hydrochloric acid are thought to have confirmed the optical identification of nephelite. The locality called Kalae is said to be in the interior of the island, at about 500 meters above the sea. I have not been able to find the name on any map of Molokai.

The rocks of this island appear to deserve much more detailed description than is given them by Möhle, and chemical investigation is specially to be desired. It seems probable that many of the lavas are nearer to trachydolerite or pyroxene andesite than to typical olivine-plagioclase basalt.

ROCKS DESCRIBED BY LINDGREN.

In his paper on the water resources of Molokai Lindgren gives but little space to the petrography. He refers to the lavas observed[3] as chiefly "normal feldspar basalt, somewhat glassy, and with olivine, occasionally also containing phenocrysts of soda-lime feldspars."

We are indebted to Lindgren for the very interesting discovery of coarsely granular "olivine diabase" in the west fork of Wailau Gulch, which penetrates to the heart of the mountains of eastern Molokai. The bed of the west fork contains many bowlders of this rock, which are thought by Lindgren to come from a large crosscutting body near the head of the gulch. The

[1] Neues Jahrb., Beilage Band 15, pp. 71-82, 1902.
[2] Characteristics of volcanoes, p. 291, New York, 1890.
[3] U. S. Geol. Survey Water-Supply Paper 77, p. 14, 1903.

diabase was not found in place and is not present in the east fork of the gulch. As described by Lindgren,[1] this interesting rock is composed of very calcic plagioclase, near anorthite, with augite, magnetite, and olivine, the last named being in much smaller quantity than the augite. By comparison of Lindgren's specimens with the sodic gabbro of Kauai they are seen to be very similar, even to the violet color of the augite.

ISLAND OF MAUI.

Maui, the next to the youngest island of the Hawaiian group, embraces about 728 square miles. It is a volcanic doublet, like Oahu, and the two mountainous parts, which are of unequal size, are known as West and East Maui. The older of these is West Maui, a huge volcanic pile some 25 miles north and south by half as much east and west. The highest central point is Puu Kukui, which has an elevation of 5,788 feet, according to the old Government map. From the vicinity of this peak valleys and ridges radiate. The deepest canyons are on the east and north sides.

Although in the main West Maui is apparently a great volcano long dead and deeply dissected by erosion, there are, as in Kauai and Oahu, numerous small comparatively modern lava and tuff cones or craters distributed over the scarred flanks of the old giant, from sea level nearly to the summit. Lava flows from some of these recent vents no doubt cover portions of the slopes in practical conformity with much older flows.

East Maui has for its central feature the great volcano of Haleakala, the irregular crater of which has often been described This enormous volcanic pile has also been deeply scored on the windward side, but many canyons appear to have been filled up, wholly or in part, by lava floods from recent vents not yet clearly identified. Still later than these flows there are, as on West Maui, many cinder and lava cones of so recent formation that their slopes have been little modified by denudation.

West Maui.

So far as I am aware, no specimens definitely representing the old central complex of West Maui have ever been described by a petrographer. I examined with some care the bowlders occurring in the stream beds of the Iao and Waihee valleys at the road crossings of these rivers near Wailuku, on the east coast. The heads of these valleys are tremendous crater-like gorges cut deep into the core of the volcano under Puu Kukui and may be supposed to reveal the character of the deeper parts of complex more extensively than the other shallower valleys.

BOWLDERS OF WAIHEE VALLEY.

Dark fine-grained or aphanitic rocks predominate in the Waihee Valley, but there are few of distinct olivine-plagioclase basalt. Some bowlders exhibit olivine and augite phenocrysts and less abundant plagioclase.

Among the types collected is a porphyritic olivine-plagioclase basalt, which is less basic than the normal. It is a dull pinkish-gray rock with many small phenocrysts of labradorite (2 to 3 millimeters) and a few of olivine, embedded in a dominant aphanitic groundmass. The holocrystalline groundmass consists chiefly of andesine microlites, augite, olivine, and magnetite. The last three average about 0.1 millimeter in diameter. Orthoclase and possibly nephelite are present in subordinate amount. The rock differs from the basalts of Oahu in that labradorite rather than olivine is its dominant phenocryst and it contains a larger amount of alkali feldspar.

Another notable type among the Waihee bowlders is a dark-gray perpatic olivine aphanophyre. Some of the olivine phenocrysts are aggregates of several grains. The groundmass is holocrystalline and consists of augite, olivine, oligoclase or andesine microlites, and magnetite, with orthoclase and nephelite in small amount. The augite, olivine, and magnetite average about 0.01 millimeter in diameter, but the rock is so fresh that each grain is clearly defined.

[1] Op. cit., p. 15.

A third type is a black, perpatic labradorite aphanophyre, the phenocrysts of feldspar ranging from minute specks to crystals having a diameter of 3 millimeters. The groundmass is holocrystalline but extremely fine, equigranular, and made up of augite, olivine (?), magnetite, and a colorless mineral, all averaging about 0.01 millimeter in diameter. The colorless mineral is apparently alkali feldspar, or perhaps in part nephelite.

BOWLDERS OF IAO VALLEY

The rocks noted in Iao Valley resemble those of the Waihee, the dark labradorite aphanophyre being common. Of particular interest is a millimeter-grained, equigranular olivine diabase of ophitic fabric and very simple composition. Olivine is much subordinate to both augite and labradorite in this rock. No orthoclase or quartz appear in the thin section. As Iao Valley heads directly under Puu Kukui this granular rock may belong to a core mass in the heart of the volcano.

ROCKS DESCRIBED BY MÖHLE.

Nearly all the rocks of the Schauinsland collection from Maui [1] were obtained near Lahaina, on the west coast. Among them is a type called augite andesite by Möhle, which he considers to be probably the same as the highly feldspathic rock described by Dana—the rock here described as soda trachyte. A silica determination yielded 61.48 per cent, agreeing closely with the 61.63 per cent reported by Dana. Möhle adds that orthoclase is present in several large grains, the determination resting on the parallel extinction and lack of twinning. The texture is described as panidiomorphic trachytoid. Besides the predominant feldspars Möhle mentions only magnetite and a prismatic mineral of wine-yellow color, thought to be augite. No biotite, hornblende, or olivine were found.

Melilite-nephelite basalt was identified by Möhle in one specimen obtained near Lahaina. It is a gray porphyritic rock, in which many of the olivine phenocrysts are large interpenetration twins. Melilite is partly developed in phenocrysts. The groundmass of melilite, nephelite, augite, and magnetite is rather coarsely granular. Perofskite is absent. The rock is said to resemble the melilite basalt of the Schauinsland collection from the vicinity of Honolulu, Oahu.

Normal plagioclase basalt is, according to Möhle, the term best describing the other rocks collected near Lahaina, 20 in number. His description however, shows that olivine is not abundant in most of them, though a few are rich in that mineral. It seems quite possible that magmas of considerable range of normative composition are represented in this group of so-called normal basalts.

A gray fine-grained basalt from Wailuku is said by Möhle to have but little olivine. This must also belong to the lavas of West Maui.

SODA TRACHYTE NEAR LAHAINA.

Occurrence and character.—E. S. Dana [2] described a rock of unusual character collected by the late S. E. Bishop from Launiupoko Hill and Mount Ball, near Lahaina. Dana quotes statements of Bishop concerning the occurrences of this rock to the effect that it seems to be a crumpled lava, whose fragments have disintegrated in part under the influence of weathering, leaving harder crustlike portions which in places assume grotesque forms. Launiupoko Hill is a cone shown on the map of West Maui as about 3 miles southeast of Lahaina. "Mount Ball," said to be "2½ miles above Lahaina," does not appear under that name on the map. It may be the hill called Paupau, on the slope east of Lahaina.

The remarkable character of this rock was duly recognized by Dana and he planned further investigation of its occurrence and composition, which has, unfortunately, not proved feasible. Material from both of these occurrences has been given to me by Prof. Dana, for examination and comparison with the trachyte of Puu Waawaa. The rock of Mount Ball is a schistose,

[1] Möhle, F., Neues Jahrb., Beilage Band 15, pp. 67-71, 1902.

[2] Am. Jour. Sci., 3d ser., vol. 37, pp. 464-466, 1889.

friable mass, easily crumbling between the fingers, and made up chiefly of silvery scalelike crystals of oligoclase. Dana described them as interpenetration twins on the Carlsbad law,

> mostly arranged parallel to the brachypinacoid and hence showing no other kind of twinning. * * * The extinction [on 010] makes an angle of a few degrees with the basal edge, varying + or − with a slight change in the direction of the section. This optical character and the further fact that the acute bisectrix is nearly normal to the brachypinacoid would make the feldspar an oligoclase.

Besides the oligoclase there is a little olivine in fragments of crystals and a little brown biotite. The silica of this rock was determined by Wheeler at 61.63 per cent.

The specimen from Launiupoko Hill is a gray compact-appearing rock containing many minute pores. It is not foliate like the rock of Mount Ball, but has, as seen under the microscope, a typical microlitic trachytic fabric with little tendency to a development of scales or flakes. The microlites are on the average 0.3 millimeter long and 0.02 millimeter wide. The fabric of this rock is illustrated by Plate III, *A* (p. 22). The maximum refractive index of the microlites is about that of Canada balsam. Between the microlites is irregular anhedral alkali feldspar with notably lower index.

The mafic constituents, which seem fairly prominent in the rock, as seen in thin sections, consist of minute irregular black specks and larger prismatic or irregular grains of brown or green color. The opaque specks, of dull metallic luster by reflected light, can not be magnetite, as the analysis shows only 0.07 per cent of FeO. They do not exhibit the brilliant luster nor red color of hematite, and their character has not been determined.

The brown constituent is cloudy and appears to be partly limonitic, but part of it has homogeneous optical behavior and extinguishes nearly parallel to the apparent vertical axis. At the ends of these crystals project small green prisms of the same orientation, and a larger growth of the green mineral is common in the prismatic zone. Isolated green particles also occur. The larger the crystal the deeper the green color, and all optical behavior indicates ægirite as the green mineral, while it is believed that the brown is acmite. If the analysis is correct these mafic elements are rich in Fe_2O_3, with TiO_2 and MnO probably more abundant than FeO. The femic molecules of the norm amount to but 7.50 per cent.

Among the analogues of this trachyte of which analyses are given in Division I of the table (pp. 63–64) is a trachyte of Sardinia, of which Dr. Washington has kindly given me permission to publish his analysis in advance of his description of the rock. It is noteworthy that in that trachyte brown and green minerals occur, which are probably of the same character as those in the rock of Maui. In the Sardinian trachyte the Fe_2O_3 is also greatly in excess over FeO.

Chemical composition.—The rock of Launiupoko Hill (Dana's No. 28) has the following composition, according to analysis by George Steiger. Its molecular ratios and norm are also given.

Analysis and norm of rock of Launiupoko Hill.

Analysis.	1	Mol.
SiO_2	61.69	1,028
Al_2O_3	17.33	170
Fe_2O_3	5.30	33
FeO	.07	1
MgO	.16	4
CaO	1.05	19
Na_2O	7.47	120
K_2O	3.47	37
H_2O-	.42	
H_2O+	1.93	
TiO_2	.67	9
ZrO_2	.16	1
CO_2	None.	
P_2O_5	.05	
S	.02	
MnO	.21	3
BaO	.07	1
SrO	.03	
	100.10	

Norm.	
Zircon	0.24
Quartz	2.88
Orthoclase	20.57
Albite	62.88
Anorthite	3.61
Diopside	.43
Enstatite	.20
Hematite	5.28
Ilmenite	.61
Titanite	.98
	97.68
Rest	2.44
	100.12

As analysis and norm indicate, this rock is a soda trachyte standing in composition very near the rock of Puu Waawaa, on Hawaii (p. 35), and, as Division I of the table (pp. 63–64) shows, its nearest analogues in chemical character are a tinguaite of Essex County, Mass., two acmite trachytes of the Crazy Mountains, Mont., a trachyte of Westerwald, in Hesse-Nassau, and the trachyte from Sardinia referred to above.

Quantitative classification—The position of the trachyte in the quantitative system is shown by the following data:

Class: $\frac{Sal}{Fem}=\frac{90.12}{7.50}=12.02I='$, persalane.

Order: $\frac{Q}{F}=\frac{2.88}{87.06}=0.03=5$, canadare.

Rang: $\frac{K_2O'+Na_2O'}{CaO'}=\frac{157}{13}=12.08=1'$, nordmarkase.

Subrang: $\frac{K_2O'}{Na_2O'}=\frac{37}{120}=0.31=4$, nordmarkose.

Symbol: I′.5.1′.4.

Its intermediate position in regard to class and rang shows a near relationship to umptekose in Class II and to laurvikose in rang pulaskase of Class I.

East Maui.

The great volcano of Haleakala, East Maui, has long been celebrated, especially for its wonderful summit crater, but the only important earlier petrographic description of its lavas is embraced in the publication by E. S. Dana [1] already cited. The specimens described by him were collected by J. D. Dana (?) and nearly all came from the central crater or near it. As my own collection contains all the earlier recognized types and is probably from the same or adjacent localities, the description may profitably consider all the material together.

To begin with, it seems probable that only comparatively recent lavas of this center are represented in the collections made. The deeper canyons not occupied by recent flows may exhibit much older lavas than any to be mentioned, and of different types. The basis for this view is presented in another place (p. 92).

The crater of Haleakala, the west rim of which has an altitude of 9,000 to 10,000 feet, is approached by trails only from the south, through the Kaupo Gap, or from the north, by a long, gentle ascent to the western rim and a descent into the crater at its southwestern extremity. My route led through the Kaupo Gap, along the full east-west length of the crater and down by the trail on the northern slope. The rocks collected by me represent the flow descending from the Kaupo Gap to the sea, several recent eruptions within the crater, and the rim rock on the west. None came from the walls of the crater. There are but two general varieties among these rocks.

PICRITIC BASALT.

Occurrence.—A black vesicular basalt whose abundant and prominent phenocrysts of augite and olivine led the elder Dana to characterize it as "augitophyric and chrysophyric" covers much of the surface sloping away from the western rim of the crater, but I do not know how far it extends down the slope. Several observers have spoken of the well-formed augite crystals which have weathered out of this rock and strew the ground in some places along the trail.

Much vesicular basalt closely resembling the rock just described is also found on the floor of the crater, according to J. D. Dana. I saw some such lava and collected a specimen of it from the north base of the cone called Namaunakeakua, beside the trail about 2 miles from the western extremity of the crater.

Description.—The dark rock is of prominent porphyritic fabric, its well-formed, fresh augite and olivine phenocrysts, many of which exceed 0.5 millimeter in diameter, lying in a sharply defined groundmass of approximately equal amount—that is, the rock is sempatic. The augite often exhibits a pale violet outer zone and is full of ferritic devitrified inclusions. The olivines

[1] Am. Jour. Sci., 3d ser., vol. 37, pp 441–467, 1889.

are unusually fresh, seldom being even stained through alteration. There are many roundish smooth-walled pores or vesicles.

The groundmass is fine grained, nearly holocrystalline, and consists of an obscure mixture of augite and magnetite with inconspicuous labradorite microlites and a few minute grains of nephelite. The feldspar is considerably less than the amount indicated by the norm calculated from the analysis, so that presumably the augite is rather highly aluminous.

Chemical composition.—This basalt from Haleakala has been analyzed by George Steiger with the result given below. The norm is also stated with the analysis.

Analysis and norm of picritic basalt from Haleakala.

Analysis.	39	Mol.
SiO_2	42.99	716.5
Al_2O_3	10.21	100
Fe_2O_3	3.01	19
FeO	10.28	143
MgO	14.61	365
CaO	12.54	224
Na_2O	1.40	23
K_2O	.52	5
H_2O-	.82	
H_2O+	1.10	
TiO_2	2.52	31
ZrO_2	None.	
CO_2	None.	
P_2O_5	.29	2
Cr_2O_3	.06	
NiO	.06	1
MnO	.17	2
BaO	None.	
SrO	None.	
	100.58	

Norm.	
Orthoclase	2.78
Albite	6.29
Anorthite	20.02
Nephelite	3.12
Diopside	32.28
Olivine	24.23
Magnetite	4.41
Ilmenite	4.71
Apatite	.67
	98.51
Rest	.98
	100.49

Qualitative classification.—This basalt is to be compared with the "ultrafemic basalt" of Mauna Loa, the porphyritic gabbro of Kilauea, and the chrysophyre of Puna, on Hawaii, to be described later, but the Haleakala rock is relatively so much richer in lime that it approaches the melilite-bearing rocks in composition. The silica, however, is so high that akermanite does not appear in the norm.

In Division XIII of the table on page 76 it is shown that one of the analyzed gabbros of Rosswein, in Saxony, a trachydolerite of the Rhöngebirge, and an essexitic gabbro of Tahiti are near analogues of this basalt. Rocks closely corresponding to the basalt from Haleakala in composition seem to be rare. With the related lavas of Hawaii it may be appropriately called picritic basalt to indicate its intermediate position between plagioclase basalts and peridotitic basalts, especially in magnesian minerals.

Quantitative classification.—The following data show the relations of this rock in the quantitative system:

Class: $\frac{Sal}{Fem}=\frac{32.21}{66.30}=0.486='IV$, dofemane.

Order: $\frac{P+O}{M}=\frac{56.51}{9.12}=6.2=(1)2$, scotare.

Section: $\frac{P}{O}=\frac{32.28}{24.23}=1.33='3$, texiare.

Rang: $\frac{(Mg.Fe)O}{CaO''}=\frac{511}{152}=3.36=2$, uvaldase.

Subrang: $\frac{MgO}{FeO}=\frac{365}{146}=2.5=2$, uvaldose.

Symbol: $'IV.(1)2.{}'_3 2.2.$

As to order, the rock is transitional between scotare and hungarare. In the latter, perpolic order, rossweinose corresponds to uvaldose, and rossweinose-uvaldose expresses the classification more accurately than a single term.

ESSEXITIC ANDESITE OR TRACHYANDESITE.

General character and occurrence.—The other rocks from Haleakala described by Dana, as well as those collected by me, appear to form a group of contemporaneous lavas of closely allied types, the general nature of which may be indicated by the term essexitic andesite or trachyandesite. They are predominantly soda-rich plagioclastic lavas with some orthoclase and nephelite and carry olivine with other mafic silicates. They might have been termed trachydolerite by Rosenbusch.

The most felsic rock of this group occurs as the principal type of the coarse breccia of White Hill (elevation, 9,870 feet), situated in the extreme southwestern angle of the crater of Haleakala. It is a dull-gray, finely banded aphyric aphanite. The banding is in general plane-parallel but wavy in detail and is clearly fluidal. Fracture surfaces nearly parallel to the banding exhibit a slight satiny sheen. The rock is nearly massive, but a few minute pores can be seen with a lens.

This rock apparently forms much of the débris of the western part of the crater, produced by explosive eruptions from several centers marked by tuff cones of gray color. It seems almost certain that J. D. Dana [1] refers to White Hill in speaking of "a cone near the place of descent" from the western rim, which is made up of "gray, compact, scarcely vesiculated rock." Probably also the "dark bluish-gray rock of uniform texture" described by E. S. Dana [2] (No. 29) came from White Hill or some adjacent cone. E. S. Dana noted the forked olivines and flakes of biotite.

J. D. Dana [3] states that "the lava of the walls [of Haleakala] is in part scoriaceous; but on the south and southwest sides it was commonly a very compact, rather light gray variety of basalt, like that of the projected blocks about some of the cones." He further states that "Pendulum Peak, near the summit, just north of the southwest corner of the crater * * * consists largely of this compact light-gray basalt, with rarely any vesiculation visible without the aid of a pocket lens." But it is plainly unwarranted to assume too positively the identity of other massive rocks with that of White Hill, in the absence of microscopical examination.

A dark-gray aphanitic rock of few small phenocrysts, poor in olivine, occurring at the summit ("von der Spitze") of Haleakala, is the only specimen from East Maui in the Schauinsland collection, described briefly by Möhle.[4]

The northern inner slopes of the great crater are dotted by many tuff cones, and here and there dikes or small plugs are notable. At one of these cones northwest of Oili Puu, in which the so-called "Crystal Cave" is situated, the breccia is largely made up of gray aphyric aphanite similar to the rock of White Hill.

North of Oili Puu, near a small spring of much importance to travelers desiring to camp in the crater, is a dike of banded aphyric aphanite. This rock is also much like that of White Hill but seems slightly more basic. It contains microphenocrysts of olivine and magnetite, the largest seen being about 0.5 millimeter in diameter, while the grains of augite, olivine, and magnetite in the holocrystalline groundmass average about 0.02 to 0.03 millimeter.

The lavas that form the floor of the eastern part of the crater and extend out through the Kaupo Gap to the sea are darker than the varieties described but have nearly the same character. They are believed to be fairly represented by two specimens obtained from a ravine west of Vieira's ranch house, situated at about 1,000 feet above the sea near the point called Pukalale, on the trail to the Kaupo Gap.

Rocks analyzed.—The gray aphyric rock of White Hill and the darker, more basaltic type of Vieira's ranch seem to represent about the extremes of these rather alkalic rocks of Haleakala, and they were accordingly chosen for chemical analysis. These two rocks will be described in some detail.

The rock of White Hill (No. 4) is almost as completely aphyric in its microscopical as in its megascopical texture, prominent crystals belonging to an early generation of apatite and magnetite being the largest components. The microphenocrysts of magnetite measure about

[1] Characteristics of volcanoes, p. 275, New York, 1890.
[2] Am. Jour. Sci., 3d ser., vol. 37, p. 463, 1889.
[3] Op. cit., p. 276.
[4] Neues Jahrb., Beilage Band 15, p. 68, 1902.

0.3 millimeter in diameter. The rock is holocrystalline and consists of dominant felsic minerals, with augite, magnetite, olivine, and apatite, named in the order of abundance. Of the felsic minerals the chief is oligoclase-andesine in lath-shaped microlites and tablets making nearly half the rock. Orthoclase is determinable in irregular tablets or interstitial particles but not in the amount contained in the norm (given below). Nephelite, too, is found in minute grains, much less in amount than is shown by the norm. Augite and olivine occur in minute prismoid, the augite having rounded ends and the olivine irregular or forked termination. This habit of olivine is very different from that observed in the basalts. A few flakes of brown biotite were noted. Apatite occurs in phenocrysts rendered dark by inclusions, and more abundantly in colorless needles. Magnetite is developed principally as a fine dust, of the second generation. There is almost no trace of alteration of the minerals named, even the olivine being for the most part unstained.

The rock exposed in a ravine west of Vieira's ranch house (No. 6) is vesicular in places, but much of it is dark and aphanitic, either aphyric or aphanophyric by virtue of small andesine phenocrysts with which olivine is in some places associated. The megascopically aphyric rock is microcrystalline and microporphyritic through phenocrysts of andesine (1 millimeter) and magnetite (0.6 millimeter). Augite and olivine are somewhat more abundant than in the type first described. Fluidal texture is expressed by the arrangement of oligoclase-andesine and augite microlites. A study of the groundmass with a high power reveals two colorless minerals, mainly in anhedral grains, forming the matrix for the better-formed microlites. One of these, of very faint birefringence, has about the same index as Canada balsam and occurs rarely in rectangular forms. This is regarded as nephelite. The other mineral has stronger birefringence but a distinctly lower index than balsam and is considered to be orthoclase or some alkali feldspar. A few irregular particles of clear glass have been noted. Orthoclase and nephelite evidently make up a far greater proportion of this rock than superficial examination would suggest, but not so large a part as the norm calculated from chemical analyses indicates. The black rock of the Kaupo Gap has the habit of the many aphanitic basalts of Kilauea and other centers, but the analysis to be given shows that the microscopical resemblance to the rock of White Hill, which is emphasized by intermediate types, is a true expression of its character. It is an olivine-bearing augite andesite, related to the essexitic lavas, though not so closely as the rock of White Hill.

Chemical composition.—The chemical character brought out by the accompanying analyses and norms shows the rocks to be far different from basalts.

Analyses and norms of essexitic andesites from Haleakala.

Analyses.					Norms.		
	4		6			4	6
		Mol.		Mol.			
SiO_2	49.55	826	51.26	854	Orthoclase	13.34	12.79
Al_2O_3	17.78	174	16.74	164	Albite	34.58	38.25
Fe_2O_3	4.65	29	2.92	18	Anorthite	15.01	12.79
FeO	5.89	82	7.11	99	Nephelite	9.09	6.25
MgO	2.49	62	2.80	70	Diopside	10.42	12.40
CaO	7.01	125	6.61	118	Olivine	3.80	5.69
Na_2O	6.12	98	5.86	95	Magnetite	6.73	4.18
K_2O	2.29	24	2.25	23	Ilmenite	3.95	4.86
H_2O+	.34		.42		Apatite	2.69	2.02
H_2O-	.29		.26				
TiO_2	2.09	26	2.57	32		99.61	99.23
CO_2	None.		Trace.		Rest	.68	.68
P_2O_5	1.10	8	.81	6			
MnO	.28	4	.23	3		100.29	99.91
BaO	.05	1	.10	1			
SrO	.08		.09	1			
Inclusive	.05		.....				
	100.06		100.03				

4. White Hill (9,870 feet) in southwest angle, crater of Haleakala. Contains also ZrO_2 0.01, FeS_2 0.03, V_2O_3 0.15, no Li_2O, NiO, or Cr_2O_3. Analyst, W. F. Hillebrand.

6. Ravine west of Vieira ranch, south of Kaupo Gap, Haleakala. Analyst, George Steiger.

Quantitative classification.—The classification of rock No. 4 by the quantitative system is indicated by the following ratios:

Class: $\frac{Sal}{Fem}=\frac{72.02}{27.59}=2.61=II$, dosalane.

Order: $\frac{L}{F}=\frac{9.09}{62.93}=0.144=(5)\ 6$, norgare. Symbol: II.(5)6.2.4.

Rang: $\frac{K_2O'+Na_2O'}{CaO'}=\frac{24+98}{53}=2.3=2$, essexase.

Subrang: $\frac{K_2O'}{Na_2O'}=\frac{24}{98}=0.24=4$, essexose.

The amount of nephelite is barely sufficient to place the rock in the lendofelic order and its true position is expressed by the compound term akerose-essexose, akerose being the corresponding subrang of the perfelic order germanare.

The ratios for rock No. 6 are as follows:

Class: $\frac{Sal}{Fem}=\frac{70.08}{29.15}=2.4=II$, dosalane.

Order: $\frac{L}{F}=\frac{6.25}{63.83}=0.098=5'$, germanare.

Rang: $\frac{K_2O'+Na_2O'}{CaO'}=\frac{118}{46}=2.56=2$, monzonase. Symbol: II.5'.2.4.

Subrang: $\frac{K_2O'}{Na_2O'}=\frac{23}{95}=0.24=4$, akerose.

Here the nephelite is less than in No. 4 and the rock falls in the perfelic order but is intermediate toward norgare.

ISLAND OF HAWAII.

CENTERS OF ERUPTION.

The island of Hawaii, the largest and most recent of the group, has, because of its active volcanoes, Mauna Loa and Kilauea, received much more attention than the others. Besides the two volcanoes mentioned there are three others that have taken part in building up the island. The oldest of these is represented by the Kohala Mountains, forming the northern peninsula of the island, a district about 21 miles long from northwest to southeast and 13 miles wide. Its highest point has an elevation of 5,489 feet above the sea. Little has been published concerning the lavas of this region beyond the fact that they appear to belong to the basalt family, with a tendency toward the andesites.

The central-western zone of the island contains Mount Hualalai, a volcanic cone rising to an elevation of 8,273 feet with a basal diameter of nearly 20 miles, but dwarfed by comparison with its gigantic neighbors, Mauna Kea and Mauna Loa, the lavas of which surround it on three sides.

The various lavas of the island will be considered in groups corresponding to the several centers of eruption.

KOHALA MOUNTAINS.

Among the specimens from Hawaii described by E. Cohen[1] in 1880, were several from the Kohala Mountains, no detail of locality being given. The rocks mentioned by Cohen as occurring in the Kohala district embrace normal plagioclase basalts rich in olivine and others which he characterizes as forming a transition to the augite andesites. He does not state how many specimens from Kohala he examined.

[1] Neues Jahrb., 1880, vol. 2, pp. 23-62.

Of the normal basalts one Kohala rock is specified [1] as containing olivine in its groundmass in addition to its occurrence as phenocrysts. The transitional rocks are described as compact or vesicular, gray in color, and connected with basalt by the constant presence of scanty olivine, and with augite andesite by the abundant basis and above all by the scarcity of augite, which is in some rocks not clearly present. Plagioclase is much more abundant than augite in all the rocks.[2] That such rocks are not normal basalts may be granted, but the argument that the scarcity of augite shows relation to augite andesite is hardly convincing.

Dana and Hitchcock in their works on Hawaiian volcanoes mention the Kohala region only with reference to its relative age and topography. Dutton makes a general statement concerning the rocks which, although based on megascopic examination alone, seems worthy of citation, for it indicates a general character for these lavas quite different from that of the other centers. Dutton remarks of the Kohala volcano: [3]

> Like all the other volcanoes of these islands its lavas belong to the basaltic group. Still they have peculiarities which serve to distinguish them from those of Mauna Kea and Mauna Loa. They appear less ferruginous and much more feldspathic. Olivine does not form, as a rule, so important a part of the mineral contents of the lavas, though in some of them it is fairly abundant. The group taken as a whole shows a tendency to approach the andesites. Extreme cases may be found in which it is difficult, apart from the general relations, to say whether they should be classed among the augitic andesites or among the normal basalts. Those intensely black, dense, and highly ferruginous lavas which are universal on Mauna Loa and Kilauea do not occur on the Kohala Mountain, so far as I have discovered.[4]

There is no statement in Dutton's report as to the extent of his observations in the Kohala Mountains, but one may infer from the text that he saw only the southern portion.

The remark by Dutton that the lavas of Kohala Mountains are more feldspathic than normal basalts and approach the andesites is confirmed by Lyons in a substantial way through his chemical analyses of two lavas. One of these (No. 3 of the rocks analyzed) Lyons [4] describes as follows: "It is a bluish-gray, compact, minutely crystalline lava, containing much feldspar and very little chrysolite, and is the prevailing rock in the Kohala Mountain, at least in the Waimea neighborhood." This type is in fact far from normal basalt in composition, as shown by the analysis quoted in the chemical discussion. The rock is a dosalane and falls in the subrang akerose of the quantitative system. Its norm contains 3.6 per cent of quartz and 82 per cent of feldspar. With the exception of the soda trachytes, it is the most salic known lava of the Hawaiian group.

The other rock analyzed by Lyons [5] "is also a lava from the Kohala Mountain, * * * a somewhat vesicular stony lava of rather light color, porphyritic with white crystals of feldspar."

The norm of the analysis of this second lava also shows some quartz, which means that the mode or actual rock can have little or no olivine. Probably it should be called augite andesite. The chemical relations of both rocks will be pointed out in the second part of this paper.

My observations on the rocks of the Kohala Peninsula are limited to what could be seen during a two hours' stop of the steamer at Mahukona, on the west coast. The gentle slopes extending from the sea for several miles back to the main axis of the Kohala Mountains appear to be made up of long, narrow lava flows from sources far up in the range. This leeward slope of the mountains is not much dissected by erosion.

The lava near Mahukona is probably well represented by specimens I obtained in a railway cut near and north of the boat landing. They are from the more massive parts of thin flows, vesicular or scoriaceous in their upper and lower zones. The rock is black, aphanitic, and almost aphyric, only a few tabular labradorite phenocrysts being visible megascopically. Under the microscope it is holocrystalline or nearly so and consists of feldspar, augite, olivine, magnetite, and apatite, named in order of abundance.

The feldspar is labradorite in the phenocrysts and andesine in the abundant microlites of the groundmass, with probably a very scanty amount of orthoclase in irregular particles.

[1] Neues Jahrb., 1880, vol. 2, p. 47.

[2] Idem, pp. 51, 52.

[3] U. S. Geol. Survey Fourth Ann. Rept., p. 171, 1884.

[4] It should be noted that Dutton's failure to contribute to the microscopical petrography of Hawaii is due to the loss of his specimens while on the way to Washington.

[5] Am. Jour. Sci., 4th ser., vol. 2, p. 425, 1896.

The andesine microlites of fluidal arrangement are separated by augite and olivine grains or prismoids with a tendency to ophitic fabric in some places and with thin wedges of ferritic glass in others.

Olivine is scarcely more prominent than in the trachydolerites of Haleakala, with which this rock exhibits close relationship. No nepheline could be detected under the microscope.

It seems not unlikely that this rock is allied to that from "Kohala Mountain" analyzed by Lyons. It may have more olivine, but it is certainly not a normal olivine-plagioclase basalt like many of the lavas of Hualalai, Mauna Loa, and Kilauea.

MOUNT HUALALAI.

Mount Hualalai is in many respects a typical basaltic volcano of the Mauna Kea type. It has very gentle slopes and its summit is characterized by a group of tuff cones and pit craters. There is no central or dominant crater of the caldera type. The last eruption of the volcano, which took place from a vent on the northwestern slope, in the early part of the last century, produced lava flows extending to the sea. It is said that more than 150 cones and pit craters may be counted on the slopes of this volcano, making its present condition much like that of Mauna Kea.

References in literature to the character of the lavas of Hualalai are scanty. Among the rocks described by Cohen [1] in 1880 are some from Hualalai which he calls normal plagioclase basalt with much olivine, while others belong to the transitional group mentioned in discussing the rocks of Kohala.

Dutton speaks of the Hualalai lavas as rich in olivine and highly ferruginous and says that they closely resemble those of Mauna Loa. Daly [2] incidentally refers to the lavas of Hualalai as mainly olivine basalt.

My observations of Hualalai were made from a cattle ranch near Puu Waawaa, on the northeastern slope, as a base. I made one trip to the summit and examined the rocks exposed on the Government road crossing the northern slope.

Basaltic lavas.—The various flows exposed on the Government road from Kailua to Waimea, as it traverses the northern slope of Hualalai at an elevation of 1,800 to 2,200 feet, are of typical basaltic appearance. They are black and more or less vesicular, and their surfaces in many places exhibit the superficial characteristics of the aa or pahoehoe flows. Where massive or finely vesicular they are olivine aphanophyres, the groundmass often being greatly in excess of the phenocrysts—that is, they are perpatic. Labradorite is commonly formed in a few phenocrysts, and augite more rarely.

The groundmasses of the rocks examined are holocrystalline and consist of plagioclase, augite, olivine, and magnetite. The feldspar is labradorite as a rule and it varies in abundance, being in some rocks much subordinate to augite and olivine. Magnetite is not notably abundant.

All other observed surface lavas of the mountain are probably olivine-plagioclase basalts, but specimens were not generally taken and microscopical examination is of course necessary for positive determination. A flow exposed in the walls of a pit crater on the north slope near the summit is a perpatic aphanophyre containing less plagioclase than is found in the flows exposed on the road below.

Dunite, gabbro, and other granular inclusions in basalt.—Some of the flows crossed by the road on the north slope of Hualalai contain numerous inclusions of granular rocks, which are of several kinds. These xenoliths are generally not much more than 1 inch in diameter, but a few considerably larger ones were seen. They are subangular or rounded, fresh, and of medium to fine grain. Their chief constituents can be recognized megascopically. It is plain that olivine, plagioclase, and pyroxene are present in very variable proportions. No fragments of lava or of rocks of exogenous origin were observed in association with these xenoliths.

The origin of the olivine-bearing rocks commonly found in basalts has been variously interpreted, but there seems to be no reason to doubt the genetic relation of these xenoliths to

[1] Neues Jahrb., 1880, vol. 2, pp. 49, 51.

[2] Jour. Geology, vol. 19, p. 304, 1911.

the basalt. They are no doubt deep-seated differentiation products of the basaltic magmas formed under unknown conditions, and are common at centers of such basic rocks. Their occurrence in the basalt of Hanapepe Canyon, Kauai, has been noted above. "Olivine bombs" have been observed by Dana, Lyons, and Möhle on Oahu, and by Daly, Hitchcock, and Dutton in tuff eruptions of Mauna Kea.

The fragments in the basalt of Hualalai are particularly abundant about 1½ miles east of McGuire's ranch on the road, but similar occurrences were noted nearer to Puu Waawaa. The varieties collected may be called dunite, wehrlite, and olivine gabbro, though the last includes transitional phases to a gabbro with some enstatite and very little olivine.

Some of the dunite fragments are fresh, pure, typical olive-green rocks with but traces of augite. Small amounts of piccotite and magnetite are included in the olivine, but magnetite and other iron oxide grains are otherwise lacking.

The wehrlite has more diallage than labradorite, and olivine is subordinate. Magnetite is lacking and so is apatite. The diallage parting is very pronounced in some augite grains.

The gabbroic rocks have labradorite or bytownite as their most abundant constituent, with augite (some of it diallagic) and olivine in variable amount. Magnetite grains are plentiful in one piece. No orthoclase, highly sodic plagioclase, hornblende, or biotite has been noted.

Basaltic xenoliths.—On the summit of Hualalai there was found a block of common basalt containing a fragment of basalt of unusual texture and some peculiarities of composition. It is a pinkish-gray fine-grained porphyry with many white specks of highly calcic plagioclase, determined as bytownite in several crystals. These spots are not single crystals, however, but represent aggregates of several grains irregularly intergrown. The groundmass is holocrystalline and consists of plagioclase, augite, olivine, brown hornblende, biotite, magnetite, and apatite. Both the hornblende and the biotite are sparingly developed and in some grains the former is intergrown with augite. The plagioclase microlites vary in composition from the highly calcic central laminæ to the strongly sodic angular projections between other mineral grains. Daly[1] refers to "projected blocks" found on the summit of Hualalai and describes one of them as an "ultrafemic gabbro" and two others as "holocrystalline equivalents of the normal olivine basalt of the island."

Trachyte of Puu Waawaa and Anahulu.—On the north-northeastern slope of Hualalai is a notable cone called Puu Waawaa, the name signifying fluted or ribbed hill, according to Hitchcock. Its base is about 3,000 feet above the sea, and it rises with very regular form for several hundred feet. This cone is much more deeply scored by radial ravines than any other one of Mount Hualalai seen by me, and the name seems to give emphasis to this feature as being unusual.

The cone of Puu Waawaa is made up of well-stratified tuffs, so far as erosion has revealed its constitution, and it may be plausibly regarded as of this character throughout. The materials appear to be all trachytic ash, pumice, and obsidian, of dark-gray color. No basalt was found in the tuff, although many fragments are dark and aphanitic and seem basaltic at first sight.

North of Puu Waawaa and separated from it by a shallow valley through which basalt streams from Hualalai and Mauna Loa have flowed is a terrace, the upper end of which is at a small cone called Puu Huluhulu. This terrace has a gently sloping surface and extends northward to an elevation of about 1,200 feet above sea level, where it abruptly ends near a point called Puu Anahulu, presenting a cliff face to the north, as it does also along its western border. On the east it merges with the lower slopes of Mauna Loa, and several lava streams, notably that of 1859, have in fact flowed out upon this terrace and tongues of lava have even passed over the western cliff.

This terrace belongs to an old topography, as may be seen even from the deck of a steamer passing along the western coast or from the road skirting the shore. Dutton noted[2] it from the road and supposed it to be proof of uplift. Where the Government road ascends the

[1] Jour. Geology, vol. 19, p. 304, 1911.

[2] U. S. Geol. Survey Fourth Ann. Rept., pp. 172, 173, 1884.

steep face of this terrace, in pits for road metal, and at many exposures along the face, it can be seen that the terrace is made up of a coarse agglomerate-like mass of trachyte bowlders or blocks, many of which are greatly decomposed, producing a light-colored clay.

The materials of Puu Waawaa and the Anahulu terrace have been described by me in detail [1] and shown to be trachyte rich in soda and containing only about 10 per cent of mafic minerals. Chemical analysis was made of the obsidian from Puu Waawaa and of the freshest rock of the terrace. Without going into petrographic details here it may be pointed out that the pitchstone has nearly the composition of several rocks of Norway, as will be clear from the analyses of analogous rocks given on page 64.

Puu Waawaa is topographically on the slope of Mount Hualalai, whose basaltic lavas surround it and bank up against it on the upper side. The relations are such as to make it probable that the unique trachytic eruption of this cone must have occurred during the epoch of Hualalai itself. The cone is more denuded than the recent cones of basaltic character scattered over the volcano, yet it has not been sufficiently eroded to permit the conception that it entirely antedates the greater mountain.

The occurrence of these trachytic rocks is plainly one of great interest in the history of the island, but present knowledge does not suffice for extended discussion.

MAUNA KEA.

It is rather remarkable that so little definite information has been published regarding the lavas of Mauna Kea, next to Mauna Loa the largest volcano of the Hawaiian Islands. Cohen, Merrill, and Daly appear to be the only petrographers who have had opportunity to study rocks from this source.

Rocks described by Cohen.—In 1876 and 1880 E. Cohen [2] described a considerable number of lava specimens from Hawaii collected for him by Dr. William Hillebrand. The greater part of this collection represented basaltic glasses from Kilauea and Mauna Loa, which had for Cohen special interest and which he described with corresponding fullness. But he also referred to massive, nearly crystalline rocks, though the group descriptions are brief and details as to locality are scanty, owing to the meagerness of the original labels. Some of these specimens came from Mauna Kea and others from Hualalai or Kohala, as has been mentioned.

The Mauna Kea rocks studied by Cohen are referred by him to normal plagioclase basalt, typical augite andesite, and a group of transitional varieties. The two normal basalts of Mauna Kea are said to differ from others of the island in that they are dense light-gray rocks with platy parting and that olivine is restricted to the groundmass.[3] The transitional varieties are described with those of Hualalai and Kohala.

Two rocks of Mauna Kea called augite andesite are described in some detail by Cohen, with the remark that in the opinion of Dr. Hillebrand they are much older than the other specimens from that mountain and probably represent the core of the volcano. The ground for this opinion is not given, but Cohen points out that the unusual character of the rocks is in itself confirmatory of Dr. Hillebrand's idea. One of these andesites is said to occur at about 450 meters below the summit. It is a bluish-black dense rock ringing like phonolite when struck. It has only a few microphenocrysts of plagioclase lying in a groundmass of plagioclase, augite, and magnetite, and a film of glass base. The second rock is greenish gray and has a groundmass like the first but contains pores filled with radiate masses of undetermined zeolites, which Cohen believes to be primary. No detail of locality is given for this variety.

Lavas collected by Preston.—In connection with studies of the density of Mauna Kea, E. D. Preston collected a number of specimens representing certain lavas of the volcano. These are briefly described by G. P. Merrill in Preston's report.[4] Through the courtesy of Dr. Merrill I have had opportunity to examine Preston's collection and the thin sections, now belonging to the United States National Museum.

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[1] Jour. Geology, vol. 12, pp. 510–523, 1904.
[2] Neues Jahrb., 1880, vol. 2, pp. 23–62.
[3] Idem, p. 49.
[4] U. S. Coast and Geodetic Survey Ann Rept., 1893, pt. 2, appendix 12, pp. 630–632.

The specimens were collected at intervals along the trail from Waimea, on the north of Mauna Kea, along the western slope of the mountain to Kalaieha in the saddle on the south, between Kea and Loa, on the trail thence to the summit, and at several places near the Waiau station occupied by Preston in his observations. Unfortunately the character of many specimens precludes satisfactory microscopical determination. Most of them are hypocrystalline, the dominant glassy or ferritic base permitting only general statements of composition. It is not unnatural to suppose that most of the specimens may come from cinder cones or local lava streams and thus represent only comparatively recent products and not the larger flows of the volcano.

All these rocks are no doubt olivine-plagioclase basalt. Their characteristic feature, compared with other basalts described thus far in this volume, is the dominance of plagioclase and augite over olivine among the phenocrysts. The plagioclase is highly calcic, and one may suspect that iron oxides are more than usually abundant in the groundmass.

Observations by Dutton.—C. E. Dutton's references to the general character of lavas of Mauna Kea apparently confirm the suggestion made above that olivine is not abundant in them. He remarks:[1]

> They [the lavas of Mauna Kea] have no great variety, but at the first glance they show a well-marked difference as compared with those from Mauna Loa. Olivine is abundant but is never seen in such excessive quantities. On the other hand, the feldspars are present in great quantity in well-marked tabular crystals, and many large crystals of augite occur. The groundmass in the majority of cases inclines to bluish gray instead of being greenish black, as in most of the lavas of Kilauea and Mauna Loa.

Near the summit cone of the mountain there occurs a dense light-gray rock long used by native Hawaiians for adzes, poi pounders, and other implements. Dutton[2] refers to it—

> as undoubtedly a basalt possessing an abundance of triclinic feldspar in exceedingly minute crystals and without olivine. It appears to be identical with a very large proportion of the basalts occurring in the western portion of the United States.

The correctness of the last remark may be questioned.

Rocks noted by Hitchcock.—The rock used for implements is also mentioned by C. H. Hitchcock,[3] but he gives no further clue to its character. At the summit cone of Mauna Kea there are, according to Hitchcock, many bomblike masses, with a core of olivine (dunite?) and an envelope of "white basaltic rock" which has a superficial resemblance to granite. It is suggested by him that this outer zone of the bombs is allied to the dense rock used for implements. Both occurrences call for investigation by a petrographer.

Rocks described by Daly.—In 1909 R. A. Daly ascended Mauna Kea, apparently by the usual route from the south, and reports[4] that from the 6,000-foot contour to about the 12,000 foot contour "The lava flows seem to be very uniformly composed of a rock species which is intermediate between typical olivine basalt and a true augite andesite." A dark-gray vesicular lava from the 11,000-foot contour, which is thought to be representative of that part of the volcano, was analyzed for Daly in the chemical laboratory of the United States Geological Survey. This analysis is quoted in the table on page 47 as No. 7. This rock has only a few very small olivine and augite phenocrysts but many more of labradorite (Ab_1An_1). The pilotaxitic groundmass is nearly free from olivine. As shown in the table of norms (p. 51), the analysis yields a little normative quartz, and by the quantitative classification the rock is an andose with more than 68 per cent of salic molecules.

The upper 2,000 feet of Mauna Kea consists chiefly, according to Daly,[5] of a rock called trachydolerite, though its analysis is very similar to that of the andesitic basalt. This dense gray rock has a few minute phenocrysts of olivine and augite and many of andesine-labradorite with more alkalic borders. Orthoclase may occur as interstitial material. Daly also gives an analysis of this rock (No. 5 of the table on p. 47). It is an andose with a little normative olivine. The analogues of these two rocks are given in Division IV of the table on page 67.

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[1] U. S. Geol. Survey Fourth Ann. Rept., p. 160, 1884.
[2] Idem, p. 164.
[3] Hawaii and its volcanoes, 2d ed., p. 52, 1911.
[4] Jour. Geology, vol. 19, p. 297, 1911.
[5] Idem, p. 299.

From Daly's observations it appears that on the surface of Mauna Kea there are lavas approaching those known in Kohala. It is not yet shown that in either mountain such lavas constitute the main mass. Daly's view that Mauna Kea consists mainly of these nonbasaltic lavas, above the level of 6,000 feet, and that such distribution speaks for gravitative differentiation is discussed in a later section of this paper (p. 89).

In both trachydolerite and andesitic basalt Daly found many lherzolitic nodules, analogous to those in the olivine basalt of Hualalai and of other localities in Oahu and Kauai that have been mentioned. These nodules are probably the same as those referred to by Hitchcock, noted above.

Other rocks on Mauna Kea.—The deep canyons near the coast on the east side of Mauna Kea give an opportunity for getting at lavas somewhat below the general surface, which has not yet been improved by any geologist. The andesites described by Cohen indicate the presence of other than nearly normal basaltic rocks in this volcano, but their significance is unknown. Dr. Hillebrand's theory that they represent the core of the mountain has no known foundation. In this connection, it is interesting to note that from his observations Preston[1] calculates the mass of Mauna Kea to have a mean density of 3.26, which is greater than that of either andesite or of the basalts collected by him.

MAUNA LOA.

Much has been written concerning Mauna Loa, the greatest of Hawaiian volcanoes still active. The phenomena of its historic eruptions are described at length by Dana, Dutton, Brigham, Hitchcock, and many other observers, but comparatively little exact information is available concerning the petrography of its lavas, except the most recent flows. This is natural, for the flows of the last century are bare, while older ones are as a rule covered by dense forests below timber line, and the difficulties besetting a study of the upper zone deter most visitors from attempting it.

No deep canyons have yet been cut into the mass of this new mountain, and probably the oldest lavas visible are those exposed in the walls of Mokuaweoweo, the summit caldera. Fortunately some attention has been given to these flows. Existing data concerning the rocks will be presented in chronologic order.

Rocks described by Cohen.—Many specimens of the Hillebrand collection, described by Cohen, appear to have belonged to Mauna Loa, but these were largely glassy rocks of recent eruptions and with a few exceptions the determinations are very general.

Olivine-rich plagioclase basalt is reported by Cohen[2] from the crater of Mokuaweoweo. A basaltic pumice belonging to the flow of 1868 was chemically analyzed by Cohen[3] and it too clearly belongs in this class. The analysis is quoted as No. 32 of the table of analyses (p. 48).

Rocks described by E. S. Dana.—About 70 specimens of Mauna Loa lavas, mainly from the crater Mokuaweoweo, were collected for J. D. Dana by Rev. E. B. Baker, of Hilo, and the description of these rocks by E. S. Dana[4] gives much valuable information. Twenty specimens came from talus from the wall between the southern and central portions of the crater, 12 from the east side of the central pit, and others from various places in and about the caldera. The most marked differences in composition noted among these rocks lie in the variable amount of olivine. Some are rich in this mineral and others contain little or none.

One of the two principal groups is described as very fine grained and nearly or quite holocrystalline, of clinkstone-like appearance. It consists mainly of plagioclase augite and magnetite. "Chrysolite * * * is absent or only sparingly present." This rock is, however, called basalt.

The other notable group is prominently chrysophyric, the olivine in some places forming one-half of the mass. These are rather basic olivine-plagioclase basalts of various textures.

A less common type of rock from Mokuaweoweo is described as "light gray in color, not vesicular, and sparingly provided with chrysolite if it is present at all, and characterized by a

[1] U. S. Coast and Geodetic Survey Ann. Rept., 1893, pt. 2, appendix 12, p. 630.
[2] Neues Jahrb., 1880, vol. 2, p. 49.
[3] Idem, pp. 34, 41.
[4] Am. Jour. Sci., 3d ser., vol. 37, pp. 441–458, 1889.

very uniform granular mixture of augite and plagioclase. A specimen taken from a vein of the western wall [of the crater] belongs here." Other localities for this type are specified. The collection included also some glassy or hypocrystalline forms, the exact composition of which is not determinable.

It is plain that the rocks of Mokuaweoweo studied by Dana must have a considerable range in chemical composition, and it seems probable that some of them are true augite andesites.

Several of the modern lava streams on the slopes of Mauna Loa are represented in the Baker collection, including those of 1843, 1852, 1855–56, 1859, 1868, 1880–81, 1882, and 1887. All these are said to be of dark-colored chrysophyric rocks belonging with the second group of the crater lavas.

Rocks described by Daly.—The flow of 1852 from Mauna Loa was crossed by Daly on the trail from Kilauea toward Mauna Kea, and he describes the rock and gives an analysis.[1] The rock is called an "ultrafemic olivine basalt" and it is said to be richer in olivine phenocrysts than any other lava seen by Daly in Hawaii. By the Rosiwal method the olivine contents are estimated at 32 per cent. An analysis of this olivine is given, showing 82.29 per cent of forsterite, 15.94 of fayalite, and 0.20 of tephroite, with 1.91 per cent of impurities. The groundmass is diabasic and contains plagioclase microlites, augite granules, magnetite, and probably ilmenite. The rock is vesicular but contains no glass.

The analysis of this rock is given under No. 38 in the table of analyses (p. 48). The position of the rock in the quantitative system is shown in the table facing page 56. Close chemical analogues of this lava are rare, the nearest being an olivine diabase of New Jersey and a picrite of the Crazy Mountains, Mont. (p. 76). The chrysophyric basalt of Puna (p. 43) is of very similar constitution. The term "picritic basalt" seems to express the general character of this rock, and it is so referred to in later pages.

Rocks collected in 1902.—In traveling from Kilauea through Kau and Kona to Mount Hualalai along the road I had opportunity to see several flows of Mauna Loa erupted during the last century. Most of these are represented in the collection studied by E. S. Dana, and I can in most cases only confirm his statements. In general these flows consist of olivine-plagioclase basalt of normal character.

The flow of 1823, crossed by the road about halfway between Kilauea and Punaluu Harbor, in Kapapala, is of the usual basaltic habit, but my specimen, taken near the eastern edge, is nearly olivine free. The rock is aphanitic, aphyric, and irregularly vesicular in subordinate degree. In thin section it appears to be made up of labradorite, augite, magnetite, and a smoky glass base, all of common basaltic habit and fabric. Olivine is very subordinate indeed. I do not know whether the flow as a whole is so poor in olivine.

Several flows from Mauna Loa which passed between Mauna Kea and Hualalai were examined where they are crossed by the road from Kailua to Waimea. The flow of 1859 is dark vesicular aphanite of normal basaltic composition. Other flows a few miles east of that of 1859 are of similar character, varying only in texture, from place to place.

Review.—The lavas of Mauna Loa, erupted during the last century, are apparently all normal olivine-plagioclase basalts with the possible exception of that of 1823, which in the single specimen examined is abnormally poor in olivine. This chrysolitic type is also represented in and about the crater of Mokuaweoweo, but many of the rocks exposed in the walls of that great caldera in 1888 are of andesitic composition, as described by Dana.

KILAUEA.

General statement.—Kilauea, perhaps the best-known basaltic volcano in the world, has been visited by a host of geologists; the history of its eruptions has been compiled by J. D. Dana,[2] Dutton,[3] Hitchcock,[4] and Brigham,[5] while the story of particular eruptions has been graphically told by many eyewitnesses. But with the exception of Dana all these writers have paid

[1] Jour. Geology, vol. 19, p. 294, 1911.
[2] Characteristics of volcanoes, New York, 1890.
[3] U. S. Geol. Survey Fourth Ann. Rept., pp. 75–219, 1884.
[4] Hawaii and its volcanoes, 2d ed., Honolulu, 1911.
[5] Bernice Pauahi Bishop Mus. Mem., vol. 2, No. 4, pp. 379–600, 1909.

attention to the physical phenomena only. The lavas are referred to as basaltic, and it is true that their characteristic external features give general confirmation to this classification. With few exceptions the described rocks of Kilauea have not been collected by the petrographers who have studied them. The most notable contributions to the petrography of Kilauean lavas are those by Cohen,[1] Silvestri,[2] and E. S. Dana.[3]

Chemical analyses which may be considered sufficiently reliable for petrographic discussion have been made to the number of 21, and several others which are not satisfactory have been published. Four of the analyses are of "Pele's hair," two of "basalt obsidian," one of material collected as molten lava, and several others are of hypohyaline rocks. Obviously all these lavas can be adequately classified only by normative study of the analyses. For this reason the results of such study, detailed in the tables of norms and normative ratios, will be used in grouping the rocks for description. A more detailed study of the Kilauean lavas, with reference to their normative character, is given in a later section of this paper (p. 60).

Megascopically, the lavas of Kilauea present the usual range of textures found in any great basaltic complex. The visible variations in olivine, augite, or plagioclase phenocrysts give no ground for referring any occurrences to another group than basalt. The aphanitic and hyaline phases are relatively more abundant than at most other centers and the hyaline rocks have received so much attention from Cohen, Krukenburg,[4] and E. S. Dana as to make them classic illustrations of basic if not of basaltic glasses.

As a rule the exact localities of the rocks of Kilauea of which microscopical and chemical studies have been made are not definitely stated. In general they belong, however, (1) to the lavas of the floor of Kilauea which have issued from the center of Halemaumau within the last three or four decades; (2) to the older lavas exposed in the walls of the main caldera; or (3) to fragments from the tuff breccia on the outer slopes. While none of the rocks are as old as those of most other volcanoes of the islands, it is of some interest to consider these groups separately.

Recent lavas.—Only the more recent lavas of Halemaumau, the active center of historic times, which are slowly filling the caldera of Kilauea, can now be seen, for the flows of 1880–1894 have covered those of earlier date.

Four recent lavas of docrystalline texture were described by E. S. Dana[5] as "dark-colored vesicular basalts, containing chrysolite but not in large amount. My own specimens correspond to this statement. From the table of norms of the 11 rock analyses representing mostly hyaline forms of these recent magmas, it appears that they all fall in Class III, the salfemanes, and 10 of them in the perfelic order germanare, while 1 is in the quardofelic order vaalare. Seven of them are similar in that their total salic contents range only from 53 to 58.1 per cent, while three have less than 50 per cent of Sal. The rocks of dominant salic contents vary somewhat in the character of the normative feldspar. Five of them are in the alkalicalcic rang camptonase. These are of nearly the same relative abundance of albite over orthoclase, four of them belonging to the dosodic subrang camptonose (III.5.3.4) and one to the persodic ornose (III.5.3.5) but so near the line that it should be called camptonose-ornose. The other three rocks with more than 50 per cent of salic molecules in their norms have relatively more anorthite but are, like the others, low in potash and are assigned to auvergnose (III.5.4.4–5), in which albite is greatly in excess of orthoclase. The lavas falling in auvergnose are much more normal basalts than those in camptonose.

The most femic of the lavas of Kilauea analyzed is a specimen of "Pele's hair" (No. 34). Its 41 per cent of normative salic molecules includes but 8 per cent of anorthite, owing to the low alumina. The percentage of diopside is correspondingly increased. The ratio of alkali feldspars to anorthite in the norm is 2.1:1. The holocrystalline form of this magma would necessarily have rather strongly alkalic plagioclase, and as the norm shows 0.8 per cent of quartz and as the olivine contents could not be high, the rock might be an augite andesite, not a basalt.

[1] Neues Jahrb., 1880, vol. 2, pp. 23–62.
[2] Com. geol. Italia Boll., vol. 19, pp. 128–147, 168–196, 1888.
[3] Am. Jour. Sci., 3d ser., vol. 37, pp. 441–467, 1889.
[4] Mikrographie der Glasbasalte von Hawaii, Inaug. Diss., Tubingen, 1877.
[5] Am. Jour. Sci., 3d ser., vol. 37, p. 458, 1889.

Five other recent lavas of Kilauea contain normative quartz, ranging from 0.8 to 8.5 per cent. It is plain that these lavas can have no large amount of olivine in their crystalline modes unless accompanied by free silica, and while they are so rich in anorthite as to make it probable that these varieties would here be called plagioclase basalt (olivine free), they are manifestly near to pyroxene andesites.

The lavas of Halemaumau do not contain normative nephelite in notable amount, contrasting in this respect with some of the rocks next to be considered.

The magma of 1911 has the composition given under No. 30 in the general table of analyses (p. 48). The material for this analysis was dipped from the basin of molten lava by Perret and Shepherd [1] and presumably represents the general character of the magma of the present period of eruption, which has now continued for several years. This magma is ornose-camptonose and transitional also to auvergnose (III.5.3(4).4(5)). It is near the average magma of Halemaumau.

Another recent lava, thought by Day to be probably that of 1894, has the composition shown by analysis 29 of the table, which is that of a specimen collected by Day. It is auvergnose (III.5.4.4–5) and nearly like other lavas of this group.

Rocks of the caldera walls.—Eight rocks of the walls of the caldera have been analyzed by Silvestri,[2] giving interesting evidence of much more diversity in chemical composition than would be suggested by the megascopic aspect of the rocks themselves. No specific data as to locality or character of the rock masses are given. As clastic rocks are rare at Kilauea, it may be plausibly inferred that Silvestri's analyses represent lava flows of the upper 200 to 300 feet of Kilauea, erupted before the present caldera was formed.

On studying the analyses by means of the norms, it at once appears noteworthy that they are nearly all of rocks more salic than any of the more recent lavas. Three of them fall in the dosalane class, although two of these are very near the salfemane line. The small amount of olivine and the general character of one of these varieties led Silvestri to call it augite andesite, while another one is described as intermediate between andesite and basalt, the scanty olivine alone preventing reference to andesite. His augite andesite contains, however, 6 per cent of normative olivine. (See No. 11 in table of norms, p. 51.)

The table of norms shows that two of the rocks under discussion belong to the subrang andose and one to salemose. One of the former is a camptonose-andose and is thus nearly related to several other lavas of Kilauea. It is rather high in orthoclase and olivine.

The two remaining dosalanes are notable as possessing normative nephelite and olivine, one of them carrying a sufficient amount of nephelite (9.7 per cent) to put it in the lendofelic order. This rock is also remarkable, if the analysis is correct, for its orthoclase content (16.7 per cent), which exceeds that of albite and is surpassed in but two known rocks of Hawaii, namely, the soda trachytes. Altogether these rocks approach the essexitic composition shown by the lavas of Haleakala, already described.

The next interesting phase of these rocks is represented by two hornblende-bearing types of kilauose (III.5.2.4). The characteristic chemical feature of these magmas is their relatively high alkali feldspars and low anorthite. One of them is near the lendofelic order in which monchiquose (III.6.2.4) is the corresponding subrang. Both rocks are also near to the essexose of Haleakala, as a glance at the norms will show. Hornblendic rocks are very rare in Hawaii, and these two types have both normative and modal peculiarities not expressed in calling them common basalts.

Two of Silvestri's "basaltoids" are camptonose of nearly the same composition. With the camptonose-andose these form a group of olivine-plagioclase basalts of no unusual features except a general high ratio of alkali feldspar to anorthite.

The remaining rock is a more calcic plagioclase basalt, but so high in silica that its norm shows 3.4 per cent of quartz. It is chemically almost identical with the lava of 1883, already mentioned. Owing to the rarity of phenocrysts of olivine, augite, and plagioclase, which Silvestri considers characteristic of true basalts, he proposes for this rock the name kilaueite.

[1] Day, A. L., and Shepherd, E. S., Geol. Soc. America Bull., vol. 24, p. 285, 1913.
[2] Com. geol. Italia Boll., vol. 19, pp. 128–147, 168–196, 1888.

The six rocks from the walls of Kilauea described by E. S. Dana [1] are olivine-plagioclase basalts with little in the brief descriptions to aid in correlating them with special types analyzed by Silvestri. One of them, from Waldrons Ledge, is unusually rich in olivine and is the most mafic lava of the volcano now known.

Fragments in the tuffs.—The slopes surrounding the caldera have a coating of volcanic ashes, in some layers of which there are many fragments of basaltic character. The collection studied by E. S. Dana contained specimens of 11 such ejected rocks, from the rim of the caldera, especially on the west side. I collected three representative types from loose fragments near the triangulation station on the north rim. The pyroclastic deposits are heaviest and most extensive to the southwest of the main caldera. J. D. Dana [2] referred this material to the last important explosive eruption of Kilauea, in 1789 or 1790, but Hitchcock [3] has pointed out that the mass of the tuff-breccia is larger than is plausibly referable to that outburst, of which accounts, obtained from the natives, have been published.

Whatever the date of eruption may be, the interest attaching to these materials in the present review lies mainly in the evidence they afford as to the petrographic character of Kilauean lavas of older date than any flows now visible. J. D. Dana,[4] who examined the tuff-breccia with care in 1887, has briefly described the megascopic appearance of the rock fragments as follows:

> The ejected stones vary in size up to several cubic feet. Those of 1 or 2 cubic feet are common, many are 20 to 30, and one seen by the author on the west side of Kilauea measured 100 cubic feet and must have weighed over 8 tons. Part are ordinary volcanic scoria, but the most of them consist of the more solid basalt, sparingly vesicular, and many of the larger are of a light-gray kind, very slightly vesicular or hardly at all so, very sparingly chrysolitic, and frequently having on the worn exterior a faint banded appearance from alternating variations in compactness of texture. Another kind varies in color from faintly reddish to gray, is more or less vesicular, and contains a large amount of chrysolite.

E. S. Dana's description [5] of material collected by his father from fragments thus described shows that there is considerable variety among them. Some are said to be coarsely granular rocks rich in olivine and labradorite and presumably containing augite and iron ore, though these are not mentioned. Other light-gray lavas contain little olivine and seem to belong to the group of rocks near to pyroxene andesite, of which several examples have been given. Some are vesicular basalts with prominent olivine.

Of the three specimens of ejected fragments collected by me, one is a common vesicular olivine-plagioclase basalt similar to some of the recent flows from Halemaumau. Another is a light ash-gray, megascopically aphyric aphanite with a few minute pores containing feldspar and ore tablets. This is no doubt like certain rocks described by E. S. Dana, the vesicles of which have tablets of labradorite and ilmenite. This rock is a very even grained, almost holocrystalline mixture of augite, labradorite, and magnetite particles of pronounced micro-ophitic fabric. Olivine is rare and the rock is essentially an aphanitic diabase.

The third fragment of my collection is a dark-gray, very dense perpatic aphanophyre. Its phenocrysts are partly discernible by the naked eye, and a hand lens shows some of them to be olivine, while the microscope proves the majority to be augite. There are a few microphenocrysts of labradorite and scattered groups of the three silicates. The groundmass is a holocrystalline granular mixture of straw-yellow augite, in almost equidimensional grains less than 0.01 millimeter in diameter, plagioclase laths 0.02 by 0.006 millimeter in average dimensions, and magnetite dust. Plagioclase seems also to be the irregular matrix of the mass. No olivine has been recognized in the groundmass.

As this rock seemed to be more basic than most Kilauea basalts and poor in olivine it was submitted to analysis, with the result given in column 33 of the table of analyses. It proves to belong in the subrang auvergnose (III.5.4.4–5) and to be considerably more basic than any lava analyzed by Silvestri. It has $\frac{\text{Sal}}{\text{Fem}} = \frac{42.9}{56.6}$ and is in this ratio near the "Pele's hair" analyzed by Cohen; but its normative plagioclase is much more calcic than that of the glass.

[1] Am. Jour. Sci., 3d ser., vol. 37, p. 459, 1889.
[2] Characteristics of volcanoes, p. 41, New York, 1890.
[3] Hawaii and its volcanoes, 2d ed., p. 168, Honolulu, 1911.
[4] Op. cit., p. 44.
[5] Op. cit., p. 460.

The norm shows 0.8 per cent of quartz, and naturally there is neither olivine nor nephelite. The rock is either a plagioclase basalt (olivine poor) or an olivine-bearing augite andesite.

Gabbro of the Uwekahuna "laccolith."—Daly [1] has described the rock of an apparently intrusive mass, a section of which is exposed in the caldera wall near the Uwekahuna triangulation station, as "porphyritic gabbro." The facts of occurrence stated by Daly do not, it seems to me, demonstrate the intrusive character of this body, said to be 20 meters thick and 160 meters wide. If intrusive the magma was injected into the thin upper zone of the volcano, while presumably some form of conduit led to the surface near by.

The rock is characterized by numerous olivine phenocrysts which reach a maximum diameter of about 4 millimeters. The groundmass is millimeter-grained as to its augite and labradorite (Ab_3An_3). The grain is thus not much coarser than that of many basaltic flows.

The modal percentage composition of the rock is estimated by Daly at olivine 40, augite 31, labradorite 27, magnetite and ilmenite 1.7, and apatite 0.3. The analysis of this rock made by Steiger, for Daly, is given under No. 42 of the table of analyses (p. 48). It is very clear that this porphyritic gabbro is almost identical in composition with the chrysophyric basalt of Puna, erupted in 1840, which is described below. It is next to the most femic rock of Hawaii thus far analyzed, and is in general near wehrlite in chemical composition, as Daly has pointed out. Division XIV of the table of analogues (p. 77) gives analyses of several analogues of this gabbro and of the basalt of Puna.

Summary.—The lavas of Kilauea exhibit much variety in chemical composition, but are predominantly olivine-poor basalts of the subrangs camptonose (III.5.3.4) or auvergnose (III.5.4.4–5). A number of the analyzed rocks have quartz in their norms. The gabbro of the Uwekahuna "laccolith" and the chrysophyre of Waldrons Ledge, noted by E. S. Dana, show that very femic magmas have also appeared at times. The lavas of the outer caldera wall show greater variation than those of Halemaumau, and there are certain apparently persistent differences between these groups of lavas (pp. 60–62). No very salic magmas are known from Kilauea.

PUNA.

The district called Puna, including the southeastern point of Hawaii and extending on the west nearly to the crater of Kilauea, is characterized by a number of cones and pit craters. Most of these lie in a narrow belt extending east-northeastward nearly the entire length of Puna. Owing to their evident connection with Kilauea, shown by activity at several points in 1840, culminating in a lava flow some 12 miles long that reached the sea at Nanawale, these minor cones of Puna are considered by Brigham [2] and other writers "a part of the Kilauea system."

Little is known as to the petrographic character of the lavas of Puna. E. S. Dana [3] refers to the highly "chrysolitic character" of the Nanawale flow of 1840 and to the small amount of olivine in the crystalline lavas of Makaopuhi, a cone in the zone referred to, near Kilauea.

The aa flow of 1840 is represented in my collection by specimens taken near the tuff "sand hills" formed by explosive action where the lava plunged into the sea, about 20 miles southeast of Hilo. This olivine-rich basalt is so different from most known Kilauean lavas that it has been analyzed and will be described in some detail.

The rock is a dark-gray chrysophyre and is variously vesicular in different parts of the flow. The specimen analyzed has abundant rounded but irregular vesicles, reaching a maximum diameter of about 1.5 centimeters and occupying about one-third of the space. No secondary minerals are present in the cavities. It seems to the unaided eye that about half the rock must be olivine, but accurate estimate is impossible because of the serial gradation from crystals 1 centimeter in diameter down to those identifiable only with the microscope. The olivine is very fresh, most of it exhibiting the characteristic clear yellowish green, while many of the larger crystals display brilliant iridescent colors. No other phenocrysts occur.

The microscope shows the groundmass to be nearly holocrystalline and of very simple composition. Besides the smaller olivine grains it is made up of augite > labradorite > magnetite,

[1] Jour. Geology, vol. 19, pp. 291–294, 1911.
[2] Bernice Pauahi Bishop Mus. Mem., vol. 2, No. 4, pp. 379–600, 1909.
[3] Am. Jour. Sci., 3d ser., vol. 37, p. 461, 1889.

with obscure opaque or dark globulitic interstitial material that plays the part of glassy base, though no actual glass has been seen. Augite occurs in grains and irregular prismoids less than 1 millimeter in diameter. The largest labradorite microlites do not exceed 0.5 millimeter in length. The maximum extinction of the labradorite microlites indicates a rather highly calcic variety. No orthoclase or nephelite has been detected. Magnetite is much obscured by the ferritic residual material in which it is embedded.

The analysis, by George Steiger, and the norm calculated from it are as follows:

Analysis and norm of olivine-rich basalt from Puna.

Analysis.	41	Mol.
SiO_2	47.25	787.5
Al_2O_3	9.07	89
Fe_2O_3	1.45	9
FeO	10.41	144
MgO	19.96	499
CaO	7.88	140
Na_2O	1.38	22
K_2O	.35	3.5
H_2O+	.08	
H_2O-	.04	
TiO_2	1.61	20
ZrO_2	None.	
CO_2	None.	
P_2O_5	.21	1
Cr_2O_3	.12	1
NiO	.09	1
MnO	.13	1
BaO	None.	
SrO	None.	
	100.03	

Norm.				
Orthoclase	1.67			
Albite	11.53	30.99		
Anorthite	17.79			
Diopside	16.22			
Hypersthene	19.45	35.67	63.03	
Olivine	27.36			68.50
Magnetite	2.09			
Ilmenite	3.04	5.13		
Apatite	.34			
	99.49			
Rest	.24			
	99.73			

The subordinate rôle of the feldspars and the abundance of magnesia in pyroxene and olivine make a distinction from common basalt desirable, and the term picritic basalt is used for this purpose. The Nanawale flow is notably similar in composition to the porphyritic gabbro of Kilauea, thought by Daly to be an intrusive. The analyses and norms of these rocks and of several analogous rocks are compared in Division XIV of the table of analogues (p. 77).

The quantitative classification of the rock is shown from the accompanying ratios:

Class: $\frac{Sal}{Fem}=\frac{30.99}{68.50}=0.452=$'IV, dofemane.

Order: $\frac{P+O}{M}=\frac{63.03}{5.13}=12.28=1'$, hungarare.

Section: $\frac{P}{O}=\frac{35.67}{27.36}=1.30=$'3, hungariare.

Rang: $\frac{(MgFe)O}{CaO''}=\frac{645}{76}=8.49=1(2)$, wehrlase.

Subrang: $\frac{MgO}{(Fe, Mn, Ni)O}=\frac{499}{146}=3.42=2$, wehrlose.

Symbol: 'IV.1'.'$_3$.1(2).2.

GENERAL DISCUSSION OF HAWAIIAN LAVAS.

INTRODUCTION.

The islands of the Hawaiian Archipelago represent the higher summits of a chain of mountains, mainly submarine, known to extend for about 1,800 miles in a general north-northwesterly direction. Soundings have shown the existence of many other mountains in addition to those whose summits now project above sea level. The ocean floor from which these mountains rise is more than 20,000 feet below the surface of the sea, but the configuration of the sea bottom is largely a matter of conjecture. Dana and others have supposed that deep troughs exist on either side of the island chain.

All the known islands of this midocean range are volcanic except for insignificant surface deposits, largely of coral reef or sand, and the volcanoes appear to be situated along a line of weakness in the submarine crust. The date at which eruptions began and the duration of the period of eruption are alike questions which can not be answered. It seems reasonable to assume that the volcanic activity has continued during all of Tertiary time, at least, and may have begun in the Mesozoic era. J. D. Dana [1] has said that "There is reason for believing that the fires along the Hawaiian line broke out all together at some time in the long past, but only Hawaii has kept on piling up lava streams from that remote time of outbreak until now, and hence has come the altitude of these lofty volcanic mountains of the Pacific." But it is certainly possible that the earliest eruptions occurred at the west end of the zone, and that in general there has been a progression in the appearance of activity at centers toward the southeast.

From the study of certain snails which are widely distributed among the islands, Pilsbry [1] has advanced the hypothesis that the present islands are the result of a subsidence which affected a large area, submerging the lower lands formerly connecting them.

The Hawaiian Archipelago appears, then, to form a very simple petrographic province. Its igneous rocks are clearly comagmatic or consanguineous, to use terms in current use. The region appears to be one especially suited to furnish the means of testing several broad generalizations of the day regarding the genetic relations of igneous rocks—generalizations based, as it seems to me, on a rather hasty survey of a great mass of undigested or disordered material from all over the earth.

A study of Hawaiian rocks will now be undertaken for the light it may throw on some of these important questions—first, the broad geographic problem involved in the original distinction of the Atlantic and Pacific branches or kindred of rocks; second, the idea of restricted genetic associations of two great series of igneous rocks, whether considered in connection with differentiation from various parent magmas or with tectonic history; third, the distinction itself, often spoken of as natural and of fundamental genetic or systematic importance, between the rock series variously designated as Atlantic and Pacific, alkali and subalkali, alkali and calc-alkali, or alkalic (alkaline) and calcic; fourth, the process of differentiation.

CHARACTERISTICS OF THE ROCKS.

MINERAL COMPOSITION.

General review.—Plagioclase, augite, olivine, and magnetite are the most important minerals in a great majority of Hawaiian rocks, and in many lavas no other constituents of note are present. The quantitative relations of these components vary greatly, as has been shown in the preceding descriptions.

Further variety is produced by the appearance of nephelite and melilite in a considerable group of younger rocks and of bronzite in the basalts of Oahu. The potash feldspar molecule is an almost constant constituent, as shown by the analyses, but it is rarely developed in recognizable form and is presumably an occult element in the plagioclase.

The alferric silicates, hornblende, and biotite are conspicuous by their absence, as a rule. The former is mentioned by Silvestri as occurring in two or three lavas of Kilauea but has not been noted by other petrographers. Biotite was observed only in insignificant development in the groundmass of one basalt of Kauai.

Ilmenite is possibly a companion of magnetite in some rocks, but the high content of TiO_2 revealed by analysis is principally concealed in augite or in titanomagnetite. Only rarely is its presence revealed by a violet color of the augite.

The simplicity in modal composition indicated by this review deserves further scrutiny if it is to be used as the basis for an adequate classification and nomenclature in the qualitative system. This is particularly true as to the composition of the plagioclase and the rôle of both occult and abnormative constituents.

Plagioclase.—Most published descriptions of Hawaiian rocks give little definite information concerning the observed plagioclase. In fact, many of the lavas examined are hypohyaline,

[1] Characteristics of volcanoes, p. 327, New York, 1890.

several of those analyzed are perhyaline, and not a few are without any noted crystals, as in the specimens of "Pele's hair." Moreover, while a part of the plagioclase is in distinct phenocrysts of labradorite or andesine, a larger part of more sodic character is present in microlites of the groundmass or in potential form in residual glass.

As it is desirable to classify these rocks, even in the qualitative system, by their real rather than their apparent characters, it is necessary to take into account the average composition of the plagioclase, which is shown, as closely as is possible, by the table of norms. Only by such a method can these lavas be systematically compared with their granular equivalents. Thus the "Pele's hair," No. 34 of the table, must certainly be considered as practically a hyaline phase of the kauaiite or olivine-bearing oligoclase gabbro (No. 26), and not simply a basaltic glass.

The approximate amount and character of the normative plagioclase may be readily seen by a glance at the percentages of albite and anorthite in the table of norms. From those figures the average or normative composition of the plagioclase may be taken as follows:

Albite in No. 2.
$Ab_{17}An_1$ in No. 1.
Oligoclase in Nos. 3, 6, 13, 26, and 34=5.
Andesine in Nos. 4, 5, 7, 8, 10, 12, 15, 16, 18, 25, 27, 28, 19, 32, 23, and 30=16.
Labradorite in Nos. 9, 11, 17, 24, 21, 20, 22, 33, 29, 14, 31, 35, 36, 38, 41, and 42=16.
Bytownite in No. 39.

It further appears that in 27 rocks the normative plagioclase has a composition between Ab_2An_1 and Ab_1An_2 with an average close to Ab_1An_1.

Now, several factors affect the agreement between this normative plagioclase and the average composition of the modal plagioclase. On the one side are two factors which tend to make the alkalic components more prominent in the mode than they are in the norm. Orthoclase is present in the mode in such subordinate amount that presumably it has been drawn with albite into the plagioclase, at least to a considerable extent. There is no biotite, and rarely hornblende, to take up potash, and potash is relatively insignificant in most analyzed augites.

Albite is doubtless directly increased over the normative percentage wherever olivine is abnormatively developed in rocks corresponding to those whose analyses show normative nephelite. This has been discussed in another place (p. 55).

The influence of these factors to raise the alkalic element of the modal plagioclase is partly offset or entirely counterbalanced by the entrance of sodic and aluminous molecules into the alferric augite. The composition of the augite of these rocks is unknown. But there is rarely evidence of the acmite molecule, and it is not to be overlooked that normative anorthite is perhaps as likely as the albite to furnish alumina for the augite.

On reviewing these factors, I regard it as probable that the average modal plagioclase of the Hawaiian basalts is at least as rich in the alkalic element as the normative plagioclase, figured from the percentages of albite and anorthite.

Lenads.—The prominence of nephelite in several rocks of Oahu, Maui, and Kauai has been sufficiently emphasized in describing them. The normative nephelite of many other rocks is usually not to be detected, and its significance has been discussed (p. 54) under the head "Relations of norm and mode." But, although so elusive, the potential nephelite, which might undoubtedly become modal under conditions of consolidation such as many rocks of equivalent composition have experienced, is an element to keep in mind in systematic discussion of the Hawaiian lavas. Leucite is prominent in the norms of three rocks of Oahu, but it has not been detected in the mode.

Quartz, tridymite, and cristobalite.—Free silica in any form has been recognized in very few Hawaiian lavas, but the norms point conclusively to the fact that many of them are, potentially at least, equivalents of quartz-bearing rocks of other regions. Certain lavas are very near to the quartz basalt of Mount Shasta in composition, and others correspond to quartz-bearing granular rocks. Tridymite was found in several rocks in very obscure development, quite unlike the aggregates which are so common in andesites and dacites. The various possible forms of free

silica are to be regarded as of much importance in many Hawaiian lavas, as showing general petrographic affiliations, and they should be looked for with due care in all holocrystalline basalts of low olivine contents and may occur in those rich in olivine, as proved by the basalt of Olokele Canyon, in Kauai.

Augite and olivine.—The augite of these rocks has common characters of basaltic augite. It is colored by the ægirite molecule in few rocks and is never very strong brown in color. It must have the general composition of the combined diopside and hypersthene molecules of the norms modified by the entrance of some soda and alumina calculated as belonging to albite and governed also by the different ratios between the FeO and MgO silicates entering respectively into augite and olivine.

Daly[1] has published the following analysis, by George Steiger, of olivine from the basic basalt of Mauna Loa, flow of 1883:

Analysis of olivine from basalt of Mauna Loa.

SiO_2	40.42
FeO	11.44
MnO	.10
NiO	.34
MgO	47.08
Inclusive	.96
	100.34

This shows about 5 forsterite to 1 fayalite. The norm of this basalt (No. 38) has olivine of the composition of about 3 forsterite to 1 fayalite. This goes to show that for this rock the augite is richer in iron metasilicate and the olivine richer in magnesian orthosilicate than the corresponding normative molecules. Very probably this relation holds good for other rocks of Hawaii.

CHEMICAL COMPOSITION.

While knowledge of Hawaiian lavas is clearly very incomplete, many varieties have been identified by microscopical examination, and there exists a really notable series of chemical analyses, so that the general character of the rocks may be seen. This character will be brought out by tables of analyses, norms, and ratios, by a diagram (Pl. IV), and by discussion of the points of most importance.

Analyses of Hawaiian lavas.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	61.69	62.19	58.06	49.55	50.92	51.26	49.73	46.30	48.71	49.01	50.16
Al_2O_3	17.33	17.43	18.21	17.78	17.59	16.74	16.39	17.95	18.87	16.29	17.97
Fe_2O_3	5.30	1.65	4.87	4.65	3.80	2.92	.7.58	6.21	3.18	7.61	2.23
FeO	.07	2.64	2.01	5.89	6.69	7.11	3.98	6.79	8.00	4.89	6.25
MgO	.16	.40	1.59	2.49	3.90	2.80	4.06	3.67	4.85	3.62	4.70
CaO	1.05	.86	3.29	7.01	6.97	6.61	7.17	8.17	9.87	9.79	11.85
Na_2O	7.47	8.28	6.12	6.12	4.28	5.86	4.12	3.92	4.15	3.82	3.50
K_2O	3.47	5.03	2.75	2.29	1.86	2.25	1.93	.89	1.52	.80	2.80
H_2O+	1.93	.39	(a)	.34	.79	.42	.54	(a)	.....	(a)	.90
H_2O-	.42	.14	.....	.29	.35	.26	.81	.....	.....	.....	
TiO_2	.67	.37	1.88	2.09	2.55	2.57	3.05	5.35	1.81	3.93	Trace.
CO_2	.....	.02	.....	None.	.....	Trace.	None.	.....	.....	.....	.....
P_2O_5	.05	.14	.65	1.10	.40	.81	.84	.53	Trace.	.49	Trace.
MnO	.21	.32	.36	.28	.20	.23	.23	.26	Trace.	.27	.30
BaO	.07	.03	.....	.05	.....	.10	.03	.....	.....	.....	.....
Inclusive	b. 21	c. 04	d. 20	e. 13	.....	f. 09	g. 07	h. 28	.....	i. 32	.....
Sum	100.10	99.93	99.99	.....	100.30	100.03	100.53	100.32	100.96	100.84	100.66

a Analysis of ignited material.
b ZrO_2, 0.16; S, 0.02; SrO, 0.03.
c ZrO_2, 0.04; traces of Cr_2O_3 and Li_2O. No S, SO_3, NiO, SrO, or V_2O_3.
d CuO, 0.10; SO_3, 0.05; S, 0.05.
e ZrO_2, 0.01; FeS_2, 0.03; SrO, 0.08; V_2O_3, 0.015. No Cr_2O_3, NiO, or Li_2O.
f SrO, 0.09. No ZrO_2, Cr_2O_3, or NiO.
g ZrO_2, 0.03; NiO, 0.04. No SO_3, S, or SrO.
h CuO, 0.17; SO_3, 0.06; S, 0.05.
i CuO, 0.10; SO_3, 0.20; S, 0.02.

[1] Jour. Geology, vol. 19, p. 295, 1911.

Analyses of Hawaiian lavas—Continued.

	12	13	14	15	16	17	18	19	20	21	22
SiO_2	45.61	49.45	51.77	47.63	48.04	47.61	45.79	49.88	48.82	49.20	50.75
Al_2O_3	15.98	13.97	15.66	15.02	14.62	16.09	15.09	13.79	15.22	14.90	16.54
Fe_2O_3	8.25	8.10	8.46	8.15	9.18	7.00	5.34	9.65	5.72	4.51	2.10
FeO	11.60	11.17	6.54	10.40	11.68	10.60	5.58	2.61	9.65	12.75	7.88
MgO	3.75	1.90	4.95	3.50	2.17	3.10	5.92	6.12	4.55	3.90	7.65
CaO	6.42	5.92	9.56	6.87	7.66	8.15	10.21	9.59	10.40	9.20	11.96
Na_2O	3.50	5.05	2.17	4.92	4.00	2.98	3.67	3.30	2.10	1.96	2.13
K_2O	1.82	1.75	.96	1.80	1.28	1.15	.90	.17	.90	.95	.56
H_2O+, H_2O-	.27	1.19	.....	.30	.....	.70	(a)	(a)	None.	.10	.35
TiO_2	1.15	Trace.	.....	.12	Trace.	.39	3.25	3.97	1.16	1.72	.....
CO_2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
P_2O_5	.72	.16	.....	.08	.45	Trace.	.29	.26	Trace.	.42	.....
MnO	1.20	.85	.82	.80	1.91	1.72	.49	.67	.67	.28	.....
BaO	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Inclusive	.....	.....	.....	.....	.....	.....	b 2.72	.....	.....	.....	.....
Sum	100.27	99.51	100.89	99.59	100.99	99.49	99.25	100.26	99.19	99.89	99.92

a Analysis of ignited material.

b SO_3, 2.54; CuO, 0.18.

	23	24	25	26	27	28	29	30	31	32	33
SiO_2	53.81	50.76	49.80	45.81	51.41	51.63	50.07	49.74	48.99	51.12	50.03
Al_2O_3	13.48	14.75	13.76	11.90	12.92	12.10	13.32	12.36	13.73	10.09	12.10
Fe_2O_3	3.02	2.89	3.09	4.62	2.87	8.67	1.92	1.64	1.60	5.35	2.10
FeO	7.39	9.85	11.97	8.09	9.29	3.10	9.28	10.08	10.46	8.59	9.97
MgO	6.46	6.54	5.02	5.39	5.45	9.40	8.01	8.83	13.53	9.68	9.57
CaO	10.34	11.05	10.25	10.67	11.46	9.17	10.64	10.88	7.34	9.72	10.58
Na_2O	3.23	2.70	3.00	4.28	2.92	3.10	2.16	2.45	1.62	3.38	2.01
K_2O	.64	.88	1.15	1.40	.70	.30	.45	.55	.27	.56	.44
H_2O+	.57	.....	.....	.53	.32	.....	.49	.17	.27	1.31	.32
H_2O-				.47			.22	.05	.10		.16
TiO_2	2.01	.....	.95	4.05	2.61	2.47	2.70	2.49	1.73	.....	2.57
CO_2	.....	.....	.....	None.	.....	.....	None.	None.	.24	.....	.....
P_2O_5	.....	.26	.22	2.20	.....	.26	.26	.41	.13	.....	.21
MnO	.....	.41	.10	.17	.16	.30	.16	.14	.20	.....	.16
BaO	.....	.....	.....	.04	.....	.....	None.	Trace.	.....	.....	.....
Inclusive	.....	.....	.....	a. 03	.....	.....	b. 28	c. 33	d. 17	.....	.....
Sum	100.95	100.09	99.31	99.65	100.11	101.08	99.97	100.08	100.38	99.80	100.22

a S, 0.03; trace of SrO. No ZrO_2, SO_3, Cr_2O_3, or Li_2O. Part of titanium may be present as Ti_2O_3, affecting figures for Fe_2O_3, FeO, and TiO_2.
b Cl, 0.08; S, 0.11; Cr_2O_3, 0.05; NiO, 0.04; traces of SrO and MoO_3. No ZrO_2, SO_3, F, or V_2O_3.
c Cl, 0.10; S, 0.04; Cr_2O_3, 0.04; NiO, 0.05; SrO, 0.07; V_2O_3, 0.02; MoO_3, 0.01.
d S, 0.04; Cr_2O_3, 0.02; V_2O_3, 0.06; NiO, 0.05. No ZrO_2, SO_3, SrO, or Li_2O.

	34	35	36	37	38	39	40	41	42	43
SiO_2	50.82	45.48	36.85	35.86	48.57	42.99	36.34	47.25	46.59	37.50
Al_2O_3	9.14	11.87	11.97	12.10	10.51	10.21	10.14	9.07	7.69	9.12
Fe_2O_3	7.37	1.98	13.90	7.82	2.19	3.01	6.53	1.45	2.20	5.59
FeO	7.03	9.87	6.54	8.09	9.45	10.28	10.66	10.41	10.46	8.81
MgO	7.22	13.28	10.73	9.72	17.53	14.61	10.68	19.96	21.79	13.72
CaO	11.63	10.97	9.00	12.08	8.06	12.54	13.10	7.88	7.41	13.85
Na_2O	3.06	2.21	4.13	6.23	1.59	1.40	4.54	1.38	1.33	2.69
K_2O	1.02	.77	.79	1.93	.34	.52	1.78	.35	.28	.63
H_2O+	1.74	.74	(a)	(a)	.37	1.10	1.00	.04	.37	2.35
H_2O-		.23			.10	.82	1.00	.08	.04	1.05
TiO_2	.....	1.90	4.05	2.90	1.48	2.52	2.87	1.61	1.83	3.21
CO_2	.....	None.	.....	.....	None.	None.	.15	None.	None.	.27
P_2O_5	.....	.25	1.25	1.08	.19	.29	1.02	.21	.11	.90
MnO	.38	.04	1.13	.39	.16	.17	.20	.13	.18	.15
BaO	.....	Trace.	.....	.....	.....	None.	.....	.....	.....	.07
Inclusive	.....	b. 19	c. 28	d 1.92	e. 18	f. 12	g. 04	h. 21	i. 25	j. 28
Sum	99.37	99.94	100.62	100.12	100.72	100.58	100.05	100.03	100.53	100.19

a Analysis of ignited material.
b FeS_2, 0.03; Cr_2O_3, 0.08; V_2O_3, 0.04; NiO, 0.04. No Li_2O or ZrO_2.
c CuO, 0.10; CoO, 0.04; S, 0.14.
d CuO, 0.25; SO_3, 0.27; FeS_2, 1.40.
e Cr_2O_3, 0.10; NiO, 0.08.
f Cr_2O_3, 0.06; NiO, 0.06. No ZrO_2 or SrO.
g S, 0.04.
h Cr_2O_3, 0.12; NiO, 0.09. No ZrO_2 or SrO.
i Cr_2O_3, 0.13; NiO, 0.12. No ZrO_2, SO_3, or SrO.
j ZrO_2, 0.02; Cl, 0.05; Cr_2O_3, 0.07; NiO, 0.04; SrO, 0.05; V_2O_3, 0.05; traces of F (?), S, and Li_2O.

ROCKS ANALYZED.

1. Soda trachyte (Cross), nordmarkose, I′.5.1′.4. Launiupoko Hill, a cone near Lahaina, west coast of Maui. Analyst, George Steiger. Specimen in Peabody Museum, Yale University.

2. Soda trachyte obsidian (Cross), nordmarkose-umptekose, (I)II.′5.1.4. Puu Waawaa, north base of Mount Hualalai, Hawaii. Analyst, W. F. Hillebrand. Specimen No. 1857, petrographic reference collection, U. S. Geol. Survey.

3. "Feldspathic lava" (Lyons), larvikose-akerose, (I)II.5.2.4. Waimea, Kohala district, Hawaii. Analyst, A. B. Lyons, Am. Jour. Sci., 4th ser., vol. 2, p. 424, 1896.

4. Trachyandesite (Cross), akerose-essexose, II.(5)6.2.4. White Hill, a cone in the crater of Mount Haleakala, Maui. Analyst, W. F. Hillebrand. Specimen No. 1860, petrographic reference collection, U. S. Geol. Survey.

5. "Trachydolerite" (Daly), andose, II′.5.3.4. Poliahu cone, near summit of Mauna Kea, Hawaii. Analyst, George Steiger. Specimen No. 1849, petrographic reference collection, U. S. Geol. Survey.

6. Trachyandesite (Cross), akerose, II.5′.2.4. Near Vieira ranch, south base of Mount Haleakala, Maui. Analyst, George Steiger. Specimen No. 1859, petrographic reference collection, U. S. Geol. Survey.

7. "Andesitic basalt" (Daly), andose, II.5.3.4. 11,000-foot contour, S. 75° E. of summit of Mauna Kea, Hawaii. Analyst, George Steiger. Specimen No. 1850, petrographic reference collection, U. S. Geol. Survey.

8. "Highly feldspathic lava" (Lyons), beerbachose-andose, II′.5.3.4(5). Waianae Mountains, Oahu. Analyst, A. B. Lyons, loc. cit.

9. "Basalto a struttura microgranitica" (Silvestri), salemose-andose, II′.5(6).3.4. Wall of caldera, Kilauea, Hawaii. Analyst, O. Silvestri, Com. geol. Italia Bull., vol. 19, p. 187, 1888.

10. "Porphyritic lava" (Lyons), andose-beerbachose, II(III).5.3′.(4)5. Kohala Mountain, northern district of Hawaii. Analyst, A. B. Lyons, loc. cit.

11. "Andesite augitica" (Silvestri), limburgose-salemose, II(III).′6.3.(3)4. Wall of caldera of Kilauea, Hawaii. Analyst, O. Silvestri, op. cit., p. 191.

12. "Basaltoide microgranitica" (Silvestri), camptonose-andose, II(III).5.3.4. Wall of caldera of Kilauea, Hawaii. Analyst, O. Silvestri, op. cit., p. 173.

13. "Orneblendafiro basaltico" (Silvestri), kilauose-akerose, II(III).5.2.4. Wall of caldera, Kilauea, Hawaii. Analyst, O. Silvestri, op. cit., p. 178.

14. Basalt stalagmite (Phillips), auvergnose-koghose, (II)III.4(5).4.4–5. In lava cave in caldera of Kilauea. Collected by Libbey. Analyst, A. H. Phillips, Am. Jour. Sci., 3d ser., vol. 47, p. 473, 1894.

15. "Basaltoide" (Silvestri), monchiquose-kilauose, (II)III.5(6).2′.4. Wall of caldera of Kilauea, Hawaii. Analyst, O. Silvestri, op. cit., p. 181.

16. "Basaltoide" (Silvestri), andose-camptonose, (II)III.5.3.4′. Wall of caldera of Kilauea, Hawaii. Analyst, O. Silvestri, op. cit., p. 175.

17. "Basaltoide" (Silvestri), auvergnose-camptonose, (II)III.5.3(4).4. Wall of caldera of Kilauea, Hawaii. Analyst, O. Silvestri, op. cit., p. 183.

18. "Pele's hair" (Lyons), ornose-camptonose, ′III.5.3.4(5). Kilauea, Hawaii. Analyst, A. B. Lyons, loc. cit.

19. Basalt (Lyons), ornose, ′III.(4)5.3′.5. Koolau Mountains, Oahu. Analyst, A. B. Lyons, loc. cit.

20. Basalt, "kilaueite" (Silvestri), auvergnose, ′III.′5.4.4–5. Wall of caldera of Kilauea, Hawaii. Analyst, O. Silvestri, op. cit., p. 185.

21. Basalt (Silvestri), auvergnose, III.′5.4.4–5. Lava of May, 1883, Kilauea, Hawaii. Analyst, O. Silvestri, op. cit., p. 135.

22. Basalt (J. D. Dana), auvergnose, III.5.4.4–5. Kilauea, Hawaii. Analysts, F. J. and O. D. Allen, Am. Jour. Sci., 3d ser., vol. 18, p. 134, 1879.

23. "Basalt obsidian" (Cohen), camptonose-ornose, III.′5.3.(4)5. Kilauea, Hawaii. Analyst, E. Cohen, Neues Jahrb., 1880, vol. 2, p. 41.

24. "Pele's hair" (Phillips), ornose-auvergnose, III.5.(3)4.4–5. Kilauea, Hawaii. Analyst, A. H. Phillips, loc. cit.

25. "Lava doleritica" (Silvestri), camptonose, III.5.3.4. Recent lava, Halemaumau, Kilauea, Hawaii. Analyst, O. Silvestri, op. cit., p. 141.

26. Kauaiite or oligoclase gabbro (Cross), kilauose, III.5′.2.4′. East branch of Waimea Canyon, Kauai. Analyst, W. T. Schaller. Specimen No. 1861, petrographic reference collection, U. S. Geol. Survey.

27. "Basalt obsidian" (Cohen), ornose-camptonose, III.5.3′.4(5). Lava of 1843, Kilauea, Hawaii. Analyst, E. Cohen, loc. cit.

28. "Traplike basalt" (Lyons), ornose, III.(4)5.3.5. Waianae Mountains, Oahu. Analyst, A. B. Lyons, loc. cit.

29. Pahoehoe basalt, auvergnose, III.5.4.4–5. Floor of Kilauea, flow of 1894 (?). Collector, A. L. Day. Analyst, J. B. Ferguson, Carnegie Geophysical Laboratory.

30. Basalt (hyaline), ornose-camptonose, III.5.3(4).4(5). Fluid lava, dipped from basin in Halemaumau, Kilauea. Collected by Perret and Shepherd, 1911. Analyst, J. B. Ferguson, Carnegie Geophysical Laboratory.

31. Plagioclase-olivine basalt (Cross), auvergnose, III.5.4.4–5. Flow, border of Olokele Canyon, Kauai. Analyst, W. T. Schaller. Specimen No. 1863, petrographic reference collection, U. S. Geol. Survey.

32. Basalt pumice (Cohen), camptonose-ornose, III′.5.(2)3.(4)5. Flow from Mauna Loa, 1868, Hawaii. Analyst, E. Cohen, loc. cit.

33. Plagioclase-olivine basalt (Cross), auvergnose, III′.5.4.4–5. Fragment in old tuff, Kilauea, Hawaii. Analyst, George Steiger. Specimen No. 1862, petrographic reference collection, U. S. Geol. Survey.

34. "Pele's hair" (Cohen), kilauose, III′.5.2′.4′. Kilauea, Hawaii. Analyst, E. Cohen, loc. cit.

35. Plagioclase-olivine basalt (Cross), camptonose-auvergnose, III′.5′.(3)4.4–5. Flow, border of Olokele Canyon, Kauai. Analyst, W. F. Hillebrand. Specimen No. 1864, petrographic reference collection, U. S. Geol. Survey.

36. "Basaltic scoria" (Lyons), monchiquose, III(IV).6′.2(3).(4).5. Cinder cone, Punahou, near Honolulu, Oahu. Analyst, A. B. Lyons, loc. cit.

37. "Black sand" (Lyons), casselose. (III)IV.2.′4.2(3).2′. Recent lapilli, Punahou, near Honolulu, Oahu. Analyst, A. B. Lyons, loc. cit.

38. "Ultrafemic olivine basalt" (Daly), palisadose-hilose, (III)IV.1(2).2′.1(2).2. Flow of 1852, Mauna Loa, Hawaii. Analyst, George Steiger. Specimen No. 1848, petrographic reference collection, U. S. Geol. Survey.

39. Picritic basalt (Cross), rossweinose-uvaldose, ′IV.(1)2.′3.2.2. Summit of Mount Haleakala, Maui. Analyst, George Steiger. Specimen No. 1866, petrographic reference collection, U. S. Geol. Survey.

40. Nephelite-melilite basalt (Cross), uvaldose-casselose, ′IV.2.(3)4.2(3).2(3). Moiliili, near Honolulu, Oahu. Analyst, George Steiger. Specimen No. 1868, petrographic reference ecollction, U. S. Geol. Survey.

41. Picritic basalt (Cross), rossweinose-wehrlose, ′IV.1′.′3.1(2).2. Flow of 1840, Nanawale, Puna. Hawaii. Analyst, George Steiger. Specimen No. 1865, petrographic reference collection, U. S. Geol. Survey.

42. "Porphyritic gabbro" (Daly), rossweinose-wehrlose, IV.1(2).3.1(2).2. Uwekahuna laccolith, Kilauea, Hawaii. Analyst, George Steiger. Specimen No. 1847, petrographic reference collection, U. S. Geol. Survey.

43. Nephelite-melilite basalt (Cross), uvaldose, IV.2.′3.2.2. Kilauea Bay landing, north coast of Kauai. Analyst, W. F. Hillebrand. Specimen No. 1867, petrographic reference collection, U. S. Geol. Survey.

Silica and alumina.—A review of the analyses of the foregoing table shows a great range for every constituent. Silica is, relatively to its total amount, the least variable of all components, in 35 out of 43 analyses falling between 45 and 54 per cent. In 25 rocks it varies less than 2 per cent from 50 per cent. Of the extreme rocks, four are notably basic, and but three are even moderately high in silica.

Alumina ranges from 18.87 per cent in No. 9 to 7.69 per cent in No. 42. The variations in alumina are quite independent of those of silica and of individual bases. This finds correct expression in the norms by the great variation in orthoclase, albite, and anorthite in rocks of similar silica contents.

Iron oxides.—Some of the determinations of the iron oxides may be more or less incorrect as to the relative amounts of Fe_2O_3 and FeO. The totals of the two oxides range from 4.29 per cent in the trachyte of No. 2 to 20.86 per cent in the "basaltoid" of No. 16. The latter rock was analyzed by Silvestri, and it is notable that in most of his analyses the total of iron oxides is higher than in those of similar rocks by other analysts. In 13 of the analyses made in the laboratory of the Geological Survey the range for the combined iron oxides is only from 10.03 to 14.40, the average being 11.93. By excluding five extreme rocks it is found that all the analyses except those of Silvestri report the iron oxides as ranging only from 9.98 to 14.40 per cent. This agreement appears to raise some question as to the accuracy of Silvestri's figures for the iron oxides, which average 15.75 per cent for 10 rocks. On the whole there is a rather remarkable constancy in the iron contents of many kinds of Hawaiian lavas.

Magnesia and lime.—Magnesia varies most notably in these rocks. Exclusive of the trachytes, Nos. 1 and 2, it ranges from 1.59 (No. 3) to 21.79 (No. 42). In 12 analyses of rocks, most of which have been called basalt by the petrographers describing them, the magnesia content falls below 4 per cent; in 9 analyses it exceeds 10 per cent. This great variation in magnesia is quite independent of the development of olivine, as will be shown in another place.

Lime is also a variable constituent, ranging from 0.86 per cent (No. 2) to 13.85 per cent (No. 43). In only 7 analyses is it reported below 7 per cent, and in 22 it exceeds 9 per cent.

Alkalies.—The alkalies taken together are very abundant in many of the Hawaiian rocks. In 16 analyses more than 5 per cent is given. The trachyte is naturally the most richly alkalic rock, but several other types, including some of the most mafic, are also rich in alkalies.

The most notable chemical characteristic of these rocks is the predominance of soda over potash. In only one rock, the "andesite augitica" from Kilauea, analyzed by Silvestri, is the reported potash molecularly equal to one-half the soda. In most of the rocks the potash is less than one-third of the soda. These molecular relations are given in the table of normative ratios, except for a few rocks in which there is some femic soda.

Minor constituents.—Of the minor chemical constituents titanic acid must be considered as highly characteristic of these lavas. In 14 analyses from the laboratory of the Geological Survey, not considering those of trachytes (Nos. 1 and 2), the range for TiO_2 is from 1.48 (No. 38) to 4.05 (No. 36), with an average of 2.44 per cent. In eight analyses by Lyons the range is from 1.88 (No. 3) to 5.35 (No. 8), with an average of 3.47 per cent. In the 22 rocks analyzed by Lyons and the Survey chemists the average for TiO_2 is 2.81 per cent. From these data it seems probable that Silvestri's determinations of TiO_2 are too low, in most cases at least. He reports a trace of TiO_2 in three rocks, a maximum of 1.81 per cent and an average for 10 rocks of but 0.73 per cent. His rocks were all from Kilauea, but all other modern analyses of rocks from that center show high contents in TiO_2. Phosphoric acid is probably present in all Hawaiian lavas, though seldom reported in noteworthy amounts. It is most abundant in the alkalic gabbro, kauaiite (No. 26), there reaching 2.20 per cent. The water content of Hawaiian rocks is decidedly low. Lyons's analyses were all made on ignited material and thus show no water. Only the analyses from the Geophysical Laboratory and the Geological Survey distinguish between water expelled above and below 110° C. In these 17 analyses the water above 110° C. is less than 1 per cent in all but the three basic rocks, Nos. 39, 40, and 43. Water expelled below 110° C. is usually of very small amount. Baryta and strontia were found in determinable amounts in most of the rocks analyzed in the Survey laboratory. Manganese is present in considerable amount in these lavas. It is notable that Silvestri reports more than 1 per cent in several rocks, while Lyons gives a corresponding amount only in the black ash of Honolulu (No. 37) and 0.32 per cent is the maximum found by the chemists of the Geological Survey in 15 analyses. Among the rarer substances ZrO_2, Cr_2O_3, V_2O_3, S, and NiO have been determined, each in several rocks. Lyons reports CuO in most of his analyses, but no other analyst has found it, and it seems possible that the copper detected by Lyons came from utensils used in his analysis. (A recent determination, by George Steiger, of the CuO in a composite sample representing 71 specimens from Hawaii yielded 0.016 and 0.015 per cent in two tests by different methods.)

It is notable that the two recent analyses of lavas from Kilauea, made by Ferguson in the Geophysical Laboratory, show Cl and MoO_3. While investigating the occurrence of molybdic acid in igneous rocks Ferguson found a trace of it in the trachyte obsidian of Puu Waawaa, using the same material which had been analyzed earlier by Hillebrand (No. 2 of table, p. 47).

NORMATIVE COMPOSITION.

The table of norms.—For the interpretation of the variations exhibited in any group of rock analyses I find it a great help to translate the analyses into norms. The accompanying table gives the norms calculated from the analyses, presented in the same order:

Norms of Hawaiian lavas.

	1	2	3	4	5	6	7	8	9	10	11
Quartz	2.9	.....	4.1	.....	.....	.....	1.7	0.3	.....	3.1	.....
Orthoclase	20.6	29.5	16.7	13.3	11.1	12.8	11.1	5.0	8.9	5.0	16.7
Albite	62.9	51.9	51.4	34.6	36.2	38.3	34.6	33.0	22.5	32.0	11.0
Anorthite	3.6	.....	12.8	15.0	23.4	12.8	20.9	28.9	28.4	25.0	25.0
Nephelite	.....	5.4	.....	9.1	.....	6.3	.....	.....	6.8	.....	9.9
Zircon	.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Corundum	.....	.....	.4	.....	.....	.....	.....	.....	.....	.....	.....
Na_2SiO_3	.....	.6	.....	.....	.....	.....	.....	.....	.....	.....	.....
Acmite	.....	4.6	.....	.....	.....	.....	.....	.....	.....	.....	.....
Diopside	.4	2.9	.....	10.4	6.8	12.4	7.1	6.3	17.2	16.0	27.8
Hypersthene	.2	.....	4.0	.....	7.3	.....	6.9	6.3	.....	1.7	.....
Olivine	.....	3.2	.....	3.8	3.2	5.7	.....	.....	9.3	.....	6.0
Magnetite	5.3	.....	2.1	6.7	5.6	4.2	4.6	6.7	4.6	5.3	3.3
Hematite	.6	.....	3.4	.....	.....	.....	4.5	1.6	.....	4.0	.....
Ilmenite	.....	.8	3.7	3.9	4.9	4.9	5.8	10.0	3.4	7.5	.....
Apatite	.....	.3	1.3	2.7	1.0	2.0	2.0	1.2	.....	1.2	.....
Titanite	1.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	97.7	99.2	99.9	99.5	99.5	99.4	99.2	99.3	101.1	100.8	99.7

Norms of Hawaiian lavas—Continued.

	12	13	14	15	16	17	18	19	20	21	22
Quartz			8.5					5.9	3.2	4.5	3.3
Orthoclase	11.1	10.6	5.6	11.1	7.8	7.2	5.6	1.1	5.6	6.1	18.3
Albite	29.3	38.3	18.3	27.8	33.5	25.2	26.2	27.8	17.8	16.8	33.6
Anorthite	22.2	10.0	30.3	13.3	18.1	27.0	22.0	22.2	29.2	28.6	
Nephelite		2.6		7.4			2.6				
Diopside	4.0	15.8	13.9	17.5	14.6	11.5	21.2	18.1	18.7	11.7	21.1
Hypersthene	3.7		12.0		7.7	14.5		6.9	14.3	21.4	16.6
Olivine	13.7	9.1		10.0	3.1	2.7	4.6				3.6
Magnetite	12.1	11.8	12.3	11.8	13.2	10.2	7.7		8.4	6.5	3.0
Hematite								9.6			
Ilmenite	2.2			.3		.8	6.2	6.8	2.3	3.2	
Apatite	1.7	.3			1.0		.7	.3		1.0	
Titanite								1.0			
	100.0	98.5	100.9	99.2	99.0	99.1	96.8	99.7	99.5	99.8	99.5

	23	24	25	26	27	28	29	30	31	32	33
Quartz	3.8				2.4	5.0	2.2				0.8
Orthoclase	3.9	5.6	7.2	8.3	3.9	1.7	2.8	3.3	1.7	3.3	2.2
Albite	27.3	23.1	25.2	29.3	24.6	26.2	18.3	21.0	13.6	28.3	16.8
Anorthite	20.3	25.3	20.6	9.2	20.0	18.3	25.0	20.9	29.2	10.8	23.1
Nephelite				3.7							
Diopside	25.2	23.0	24.2	23.8	30.3	19.9	21.2	25.0	5.1	30.1	22.9
Hypersthene	11.8	10.5	7.0		9.3	14.3	20.9	16.9	36.8	10.6	25.6
Olivine		8.0	8.3	4.8				4.6	7.2	7.5	
Magnetite	4.4	4.4	4.6	6.7	4.2	5.1	2.8	2.3	2.3	7.7	3.0
Hematite						5.1					
Ilmenite	3.8		1.8	7.6	5.0	4.7	5.2	4.7	3.2		4.8
Apatite		.5	.5	5.0		.6	.6	1.0	.3		.3
	100.5	100.4	99.4	98.4	99.7	100.9	99.0	99.7	99.4	98.3	99.5

	34	35	36	37	38	39	40	41	42	43
Quartz	0.8		4.5							
Orthoclase	6.1	4.5	4.5		2.2	2.8		1.7	1.7	
Albite	25.7	12.8	10.0		13.6	6.3		11.5	11.0	
Anorthite	8.1	20.6	12.2		20.3	20.0	1.7	17.8	14.7	11.1
Nephelite		2.9	13.4	28.1		3.1	21.0			12.2
Leucite				8.7			8.3			2.6
Acmite				.5						
Diopside	39.8	26.4	19.4	13.4	14.9	32.3	17.4	16.2	16.8	31.0
Hypersthene	6.4				23.9			19.5	17.9	
Olivine		24.5	12.5	16.3	18.7	24.2	20.2	27.4	30.8	18.6
Akermanite				12.2			12.0			3.9
Magnetite	10.7	3.0	13.0	11.1	3.3	4.4	9.5	2.1	3.3	8.1
Hematite			5.0							
Ilmenite		3.7	7.7	5.5	2.9	4.7	5.5	3.0	3.5	6.1
Apatite		.5	2.7	2.7	.4	.7	2.4	.3	.3	2.0
Chromite									.2	
	97.5	98.9	100.4	98.5	100.2	98.5	98.0	99.5	100.2	95.6

NOTE.—The norms of analyses published in Washington's Tables have been recalculated in order to show apatite and use MnO, BaO, SrO, etc., which were sometimes disregarded in the original calculations.

Object of normative study.—For the benefit of petrographers who have not utilized the norm as a means of studying rock analyses, it may not be superfluous to point out again that the analysis of an igneous rock represents as completely as is now possible the composition of a former magmatic solution which under certain physical conditions has solidified into that rock—hyaline, hypohyaline, or crystalline. A magmatic solution is a most complex system which, as crystallization progresses, naturally suffers many changes corresponding to those of attendant conditions, especially of temperature. Now, it is well known that many magmas may resolve into more or less markedly different mineral combinations or modes under the influence of

varying and little-understood conditions. Yet the general laws of chemical affinity control the result of crystallization to a high degree, and the norm is a set of standard mineral molecules, chosen with regard to the laws of chemical affinity, into which all rock analyses may be translated for purposes both of comparison and of classification. In fact, the normative molecules are chiefly those which many petrographers regard as present in the magmatic solution shortly prior to consolidation, if not at that time. Moreover, the normative molecules correspond to those of the mode to a much greater extent than many petrographers realize.

Salic molecules.—On taking the elements of the norm in order, it appears at once a striking feature of these basaltic rocks that 13 of them contain normative quartz, and that the rocks so characterized are not as a group the ones richest in SiO_2 or salic molecules. This feature is discussed in another place.

Orthoclase occupies the subordinate place determined by potash. Albite is notably prominent, as a rule. By taking nephelite and albite together the strong sodic character of the group is made very clear.

Nephelite appears in 15 norms, indicating insufficient silica for the formation of albite, but the abnormative mode as regards this constituent is one of the interesting points to be discussed elsewhere.

Leucite appears in but three norms, and these of very basic rocks.

Femic molecules.—Diopside, which depends on the excess of lime after anorthite and apatite, is found in all but one norm—No. 3. The rock is one analyzed by Lyons and is briefly described as rich in feldspar and poor in olivine.

Hypersthene occurs in all norms except those with nephelite and varies greatly in importance, being at a maximum of 36.8 per cent in No. 31. It is usually rich in magnesia, and in some norms has no iron. This may be due to analytical errors as regards the determination of iron oxides.

Olivine is highly variable, and is in many norms less than in the mode of the rocks analyzed, a discrepancy to be commented on in discussing relations of norm and mode.

The total of iron-bearing oxides is small in many norms, and yet it is higher than it should be in all those where Fe_2O_3 has been erroneously determined in excess, as may be assumed to be the fact in some of the analyses. The ilmenite, which runs unusually high, corresponds with the abundance of TiO_2 in the analyses.

Apatite is variable, rising to 5 per cent in the alkalic gabbro of Kauai and appearing to the amount of about 2 per cent in some of the more alkalic rocks. It is very low in most of the notably basic lavas, but becomes prominent in the recent and relatively alkalic nephelite-melilite basalt and similar rocks near Honolulu

Diagram of norms.—The norms are graphically expressed in a new form of diagram (Pl. IV), which also shows the distribution of the rocks in Classes II, III, and IV of the quantitative system. This diagram is simply a rectangle the diagonal of which expresses the possible variation of salic (Sal) and femic (Fem) components from 0 to 100 per cent. The scale and form of the rectangle may, of course, be suited to the needs of special cases. The norms being recalculated to 100 per cent, where necessary, the position of a given rock in this diagram is shown by the percentage of Sal or Fem. From the point on the base of the rectangle thus determined an ordinate may be drawn which will be divided by the diagonal into parts corresponding to the amounts of Sal and Fem. The elements of Sal and Fem may then be laid off additively on this ordinate. The norm may be represented by all the molecules stated or by groups of these, or the chemico-mineral character may be expressed in greater detail by using the constituent parts of compound molecules, such as diopside, hypersthene, and olivine.

In the accompanying diagram the salic molecules are shown as in the norms, but the femic silicates have been split into lime, iron, and magnesia metasilicates and orthosilicates. The sum of the metasilicates equals diopside and hypersthene; that of the orthosilicates equals olivine. The arrangement of the diagram is such as to show readily the total of lime and magnesia silicates, through placing anorthite and wollastonite together, and enstatite and forsterite. The iron

metasilicate is placed between those of lime and magnesia; but fayalite comes next to magnetite, which is followed by hematite and ilmenite, so that all the iron-bearing molecules come together except the metasilicate. By placing akermanite next to anorthite, when it occurs, all lime-bearing molecules come together except the subordinate apatite.

By this diagram the normative mineral character of the whole series of analyses, which is useful as an interpretation of the chemical statement, is brought out in a striking manner.

It may be well to call attention to the fact that the quartzose orders 4, 3, etc., may be readily distinguished on this diagram from the perfelic order 5, when the salic part of the norm is free from corundum. If the normative quartz is plotted next to the upper boundary of the diagram, lines may be drawn through the sections of Classes I, II, and III, representing 12.50 and 37.50 per cent of normative quartz. These lines represent the limits of the quardofelic order 4, as against the perfelic order 5 on the one side and the quarfelic order 3 on the other. Orders 2 and 1 can obviously also be expressed by the lines representing 62.50 and 87.50 per cent of normative quartz in the salic division.

RELATION OF NORM AND MODE.

The Hawaiian rocks range from those in which feldspars greatly predominate, and for which norm and mode must be in practical agreement, to those which are rich in augite and olivine, and for which several conditions lead to marked divergence between norm and mode. This divergence is due partly to the abnormative character of the alferric augite, partly to the entrance of FeO and TiO_2 into the augite, instead of forming the full amount of normative magnetite and ilmenite, and partly to a greater development of olivine than is necessary considering the amount of silica present. Other minor causes of variation are to be recognized.

Quartz.—The appearance of quartz in the norms of 13 rocks raises at once the query whether the silica determinations in the analyses concerned are correct. But there seems to be no good reason for casting suspicion on these figures, for the normative quartz is not especially prominent in those rocks that have the highest silica contents. Eight of the 13 rocks are from Kilauea, and were analyzed by Cohen (3), Silvestri (2), Phillips (1), Steiger (1), and Ferguson (1). These rocks of Kilauea embrace the kilaueite of Silvestri, from the outer caldera wall, one fragment in tuff, and several modern flows from Halemaumau, including those of 1843, 1883, and 1894. The five rocks analyzed by Lyons which show normative quartz include bronzite basalts of Oahu and highly feldspathic lavas of the Kohala Mountains.

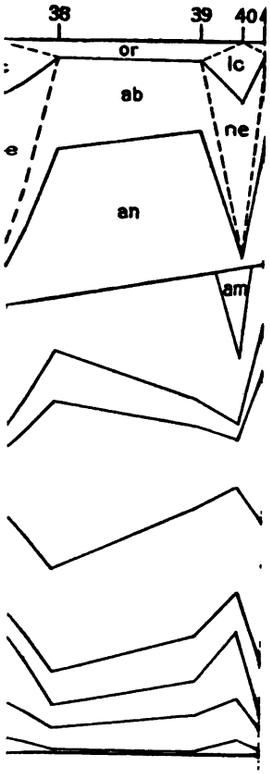
If the normative quartz is due to analytical errors, the mistake is more likely to lie in an excessive amount of ferric oxide. Such an error results in the appropriation of an undue amount of FeO for magnetite. The analyses of Lyons are especially subject to this suspicion.

By the normative calculation FeO is assigned to Fe_2O_3 and TiO_2 in the ratio 1:1 before any FeO is allotted to a femic silicate. No doubt the silicates are richer in FeO than appears in the norm, but it is to be remembered that TiO_2 also enters into the silicates with the FeO, and hence the amount of SiO_2 needed for the augite is perhaps no greater than that allotted in the normative calculation.

As an offset to the possible decrease of free silica comes the increase where olivine is developed in the rock in excess of the normative figure. As has been shown in the case of the basalt of Olokele Canyon, Kauai, this may result in the presence of abnormative, modal free silica. It is believed that this excessive development of olivine is common among Hawaiian rocks and that in consequence free silica in some form must be present in many of them, even where it would not appear in the norm.

No modal quartz or tridymite has been reported from the rocks whose analyses show normative quartz, but several of them were partly hyaline. The obscure development of tridymite and cristobalite in the chrysophyre of Kauai gives a warning that free silica may readily be overlooked where the assumption of its occurrence might be considered as painfully heterodox.

Feldspars and lenads.—As to the feldspars, the norms must represent nearly the modal composition, except for isomorphous mixture. Micas being absent and hornblende being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known only in two rocks described by Silvestri, augite is the only alferric silicate whose presence can materially interfere with the development of the feldspars in the normative proportions. Analyses of augite from Hawaiian lavas are not at hand, but in many of them this mineral has the characters of varieties presumably not rich in alumina and the alkalies.

Orthoclase doubtless occurs in part in solid solution in the plagioclase and in part in minute unrecognized interstitial particles or in the vitrophyric base of many rocks.

Leucite has not been observed, but is certainly a potential constituent of a few lavas and must appear where such rocks are holocrystalline.

Nephelite, which appears in 15 norms, is probably present in the mode of but few rocks, aside from the nephelite and melilite basalts of the basic end of the series. Its absence from rocks like many of those analyzed may be directly accounted for in two ways. In the first place, an abnormative development of olivine in any rock with normative nephelite must free silica which would very probably be utilized in turning a certain amount of normative nephelite into albite. In the second place, it appears probable that the normative nephelite may be concealed as carnegieite in solid solution in plagioclase. The possibility of such occult molecules, to use Iddings's expressive term, is certainly to be taken into account in studying the relations of norm and mode. The norm may prove to be an important aid in the detection of such occult constituents.

Nephelite was observed in the flow from Haleakala as represented by the specimen from Vieira's ranch (No. 6), but in less amount than appears in the norm of this rock.

Pyroxenes.—The acmite or ægirite molecule appears in the norm of but one rock, namely, the trachytic obsidian of Puu Waawaa (No. 2), a rock which would no doubt exhibit some alkalic and ferric pyroxene or amphibole were it to be found in fresh, holocrystalline state. The ægirite molecule is visible in part of the augite of the granular kauaiite (No. 26) and appears also in the soda trachyte of Maui (No. 1).

The combined normative diopside and hypersthene of these rocks must represent approximately the modal augite with some aluminous and alkalic molecules added thereto. Titanium also doubtless enters into the augite, but seldom betrays itself by a pinkish color, as in the kauaiite.

Olivine.—The abnormative development of olivine in many Hawaiian lavas has been referred to in several places, especially with reference to its effect upon the occurrence of quartz, or some other form of free silica, and of nephelite. It appears to be a notable feature of the Hawaiian lavas that olivine occurs in greater abundance than it would if the available silica of the magma had been utilized to produce compounds of the highest possible silicity—the assumption at the base of the normative calculation. Such excess of olivine must be accompanied by a decrease in the metasilicate expressed in the norm as hypersthene.

Akermanite and melilite.—Akermanite appears in three norms (Nos. 37, 40, 43) and corresponds to the development of melilite, though not an accurate expression of its abundance. The akermanite molecule is here, as in many other rocks, a serviceable though not entirely satisfactory representative in the norm of the complex modal melilite.

CLASSIFICATION.

QUALITATIVE SYSTEM.

An appropriate classification and naming of Hawaiian lavas by the current mineralogical or qualitative system is a task of great difficulty. They belong mainly to the general family of basalts, but even here arises the question, vital to adherents of the Rosenbusch system, whether they are true basalts or trachydolerites. Apparently it is inadmissible to say that both occur together, and I must leave this problem for those who believe in a distinction of alkalic and calcic members of the great basaltic group, with reference to data bearing on this point presented in later sections of this discussion.

In these lavas each of the essential elements of basalt, plagioclase, augite, and olivine varies in amount from dominance almost or quite to disappearance. The character of plagioclase

varies from calcic labradorite to andesine or oligoclase. Considering the rarity or absence of olivine in some of the lavas, Cohen, E. S. Dana, Lyons, and Silvestri have called certain rocks andesite or pointed out the gradation to andesite. If the character of the plagioclase is taken in account in deciding whether rocks poor in olivine are basalts or andesites, one encounters the difficulty that the more distinct feldspars are apt to be labradorite where chemical analysis shows that much sodic feldspar and some orthoclase must be in the obscure or hyaline matrix.

Of the 43 rocks analyzed, 16 have normative labradorite and the same number andesine. Although the tendency appears to be marked to introduce greater precision into current system by recognition of quantitative factors, this tendency has not gone far enough to meet the requirements of the variations exhibited by the Hawaiian lavas of the basaltic group.

In Part II of Iddings's work on igneous rocks he proposes certain names intended to give greater precision to mineralogical classification. Among these are several terms derived from Hawaii. Thus hawaiite [1] is proposed for salfemic andesine basalts. This refers to normative andesine and implies an estimate, at least, of chemical composition. By this definition Nos. 15, 16, 18, 19, 23, 25, 27, 28, 30, and 32 belong to hawaiite, when they also carry olivine. Several of them, however, are hyaline, and one must refer to their chemical composition for this classification.

As has been stated elsewhere in this paper, Iddings has further proposed the names kohalaite [2] for a dosalic oligoclase andesite and kauaiite [3] for an oligoclase-augite diorite, referring in these cases also to the average or normative plagioclase.

The more felsic and more mafic lavas of Hawaii are more readily named than the feldspar basalt group, and their classification need not be specially discussed here, except to refer to the uncertainty as to whether such rocks as the dosalanes of Haleakala (Nos. 4 and 6) and Mauna Kea (Nos. 5 and 7) are, under the circumstances, alkalic or calc-alkalic, in the Rosenbusch sense. For instance, a disciple of Rosenbusch could not accept both of Daly's names (andesitic basalt and trachydolerite) for the allied lavas of Mauna Kea.

QUANTITATIVE SYSTEM.

The detailed quantitative classification of all rocks analyzed is shown in the accompanying table of normative ratios and symbols. This has been carried out with a fivefold subdivision of certain subrangs and subgrads where the threefold subdivision would have been sufficient for the purpose of applying the quantitative names. The purpose of this detail is to bring out more uniformly and clearly in the symbols certain characteristic chemical features of these rocks. For the same reason the divisions of Class IV have been transposed in the table to bring the ratios and symbols for each normative datum in one column. The expression of transitional and intermediate relations in the symbols by the use of parentheses and accent marks, respectively, accords with the recent proposal of the authors of the quantitative system. [4] The quantitative names, with numbers corresponding to those in the table, are given below.

Quantitative system names.

1. Nordmarkose.
2. Nordmarkose-umptekose.
3. Larvikose-akerose.
4. Akerose-essexose.
5. Andose.
6. Akerose.
7. Andose.
8. Beerbachose-andose.
9. Salemose-andose.
10. Beerbachose-andose.
11. Limburgose-salemose.
12. Camptonose-andose.
13. Kilauose-akerose.
14. Auvergnose-koghose.
15. Monchiquose-kilauose.
16. Andose-camptonose.
17. Auvergnose-camptonose.
18. Ornose-camptonose.
19. Ornose.
20. Auvergnose.
21. Auvergnose.
22. Auvergnose.
23. Camptonose-ornose.
24. Ornose-auvergnose.
25. Camptonose.
26. Kilauose.
27. Ornose-camptonose.
28. Ornose.
29. Ornose-camptonose.
30. Auvergnose.
31. Auvergnose.
32. Camptonose-ornose.
33. Auvergnose.
34. Kilauose.
35. Camptonose-auvergnose.
36. Monchiquose-(unnamed).
37. Casselose.
38. Palisadose-hilose.
39. Rossweinose-uvaldose.
40. Uvaldose-casselose.
41. Rossweinose-wehrlose.
42. Rossweinose-wehrlose.
43. Uvaldose.

[1] Igneous rocks, pt. 2, p. 198, New York, 1913. [2] Idem, p. 193. [3] Idem, p. 173. [4] Jour. Geology, vol. 20, pp. 554–557, 1912.

Normative ratios and symbols.

Classes I and II.—Persalanes and dosalanes.

No.	Class. $\frac{Sal}{Fem}$	Order. $\frac{Q-L}{F}$	Rang. $\frac{Alk}{CaO'}$	Subrang. $\frac{K_2O'}{Na_2O'}$	Grad. $\frac{P+O}{M}$	Section of grad. $\frac{P}{O}$	Subgrad. $\frac{(Mg,Fe)O}{CaO''}$	Section of subgrad. $\frac{MgO}{FeO}$	Symbols.							
									Class.	Order.	Rang.	Subrang.	Grad.	Section of grad.	Subgrad.	Section of subgrad.
1	12.02	0.03	12.08	0.31	0.11	.....	.....	.....	I′	5	1′	4	.....	.....	.....	.....
2	6.97	.066	∞	.45	14.9	2.50	3.40	2.44	(I)II	5′	1	4	1′	2	2	2
3	5.89	.05	2.78	.33	.44	∞	5.61	1.21	(I)II	5	2	4	4	1	(1)2	3
4	2.61	.144	2.30	.24	1.33	2.74	2.00	.72	II	(5)6	2	4	′3	2	2′	3′
5	2.46	.00	.94	.29	1.65	4.43	4.84	1.05	II	5	3	4	(2)3	′2	′2	3
6	2.4	.098	2.56	.24	2.00	2.18	3.74	.69	II	5′	2	4	2′	2′	2	3′
7	2.20	.025	1.14	.30	.94	∞	3.02	1.76	II	5	3	4	3	1	2	2(3)
8	2.09	.004	.69	.143	.69	∞	4.63	.94	II′	5	3′	4(5)	3′	1	′2	3
9	1.93	.113	.81	.24	3.31	1.85	3.10	1.09	II′	5(6)	3	4	2	2(3)	2	3
10	1.83	.05	.77	.15	1.04	∞	1.94	1.26	II(III)	5	3′	4(5)	3	1	2′	3
11	1.72	.182	.95	.54	10.40	4.67	1.73	1.30	II(III)	′6	3	(3)4	1′	′2	2(3)	′3
12	1.70	.00	.95	.36	1.49	.56	8.00	.53	II(III)	5	3	4	(2)3	(3)4	1(2)	(3)4
13	1.66	.04	2.81	.24	2.11	1.74	3.10	.28	II(III)	5	2	4	2′	2(3)	2	4

Class III.—Salfemanes.

14	1.64	0.156	0.41	0.29	2.11	∞	3.63	1.24	(II)III	4(5)	4	4	2′	1	2	3
15	1.50	.1418	2.06	.25	2.27	1.75	3.24	.57	(II)III	5(6)	2′	4	2	2(3)	2	(3)4
16	1.50	.00	1.20	.22	1.92	7.2	3.42	.33	(II)III	5	3	4′	2′	1(2)	2	4
17	1.49	.00	.63	.27	2.61	9.71	5.08	.456	(II)III	5	3(4)	4	2	1′	′2	′4
18	1.39	.05	.87	.17	1.86	4.57	2.18	1.70	′III	5	3	4(5)	2(3)	′2	2′	2(3)
19	1.33	.115	.69	.04	1.52	∞	2.36	3.40	′III	(4)5	3′	5	(2)3	1	2	2
20	1.28	.06	.42	.29	3.10	∞	3.17	.79	III	5	4	4	2	1	2	3
21	1.28	.09	.42	.34	3.42	∞	5.47	.54	III	′5	4	4	2	1	′2	(3)4
22	1.25	.00	.34	.17	13.65	10.58	3.22	1.75	III	5	4	4(5)	1	1′	2	2(3)
23	1.22	.07	.81	.13	4.50	∞	3.36	1.57	III	′5	3	(4)5	′2	1	2	(2)3
24	1.16	.00	.59	.23	9.41	4.14	3.07	1.15	III	5	(3)4	4′	1(2)	2	2	3
25	1.14	.00	.82	.37	6.11	3.75	2.68	.75	III	5	3	4	(1)2	2	2	3′
26	1.05	.08	2.55	.22	2.00	4.94	1.58	1.18	III	5′	2	4′	2′	′2	(2)3	3
27	1.04	.05	.75	.15	4.30	∞	2.01	1.04	III	5	3′	4(5)	2	1	2′	3
28	1.03	.11	.80	.06	2.28	∞	3.13	4.43	III	(4)5	3	5	2	1	2	′2
29	.95	.05	.44	.137	5.30	∞	3.31	1.52	III	5	4	(4)5	(1)2	1	2	2(3)
30	.827	.00	.613	.15	6.62	9.03	3.03	1.556	III	5	3(4)	4(5)	1(2)	1 (2)	2	3
31	.81	.00	.28	.11	8.95	5.82	18.7	2.28	III	5	4	(4)5	1(2)	(1)2	1	2
32	.76	.00	1.54	.11	6.30	5.41	2.69	2.03	III′	5	(2)3	(4)5	(1)2	(1)2	2	2′
33	.76	.02	.43	.12	6.16	∞	3.58	1.70	III′	5	4	(4)5	(1)2	1	2	2(3)
34	.72	.02	2.07	.22	4.32	∞	1.58	1.77	III′	5	2′	4′	2	1	(2)3	2(3)
35	.70	.08	.58	.23	7.56	1.09	3.86	2.39	III′	5′	(3)4	4′	1(2)	3	2	2
36	.66	.50	1.68	.12	1.24	1.56	3.20	2.50	III(IV)	6′	2(3)	(4)5	3	(2)3	2	2

Class IV.—Dofemanes.

No.	Class. $\frac{Sal}{Fem}$	Grad. $\frac{L}{F}$	Subgrad. $\frac{Alk}{CaO'}$	Section of subgrad. $\frac{K_2O'}{Na_2O'}$	Order. $\frac{P+O}{M}$	Section of order. $\frac{P}{O}$	Rang. $\frac{(Mg,Fe)O}{CaO''}$	Subrang. $\frac{MgO}{FeO}$	Symbols.							
									Class.	Grad.	Subgrad.	Section of subgrad.	Order.	Section of order.	Rang.	Subrang.
37	0.596	∞	∞	0.20	2.55	0.49	1.69	2.01	(III)IV	9	1	4′	2	′4	2(3)	2′
38	.563	0.0	0.41	.15	9.37	2.08	8.53	3.57	(III)IV	5	4	4(5)	1(2)	2′	1(2)	2
39	.49	.11	.39	.22	6.20	1.33	3.36	2.50	′IV	5(6)	4	4′	(1)2	′3	2	2
40	.46	17.5	15.5	.26	3.10	.54	1.86	1.77	′IV	9	1	4	2	(3)4	2(3)	2(3)
41	.452	.0	.39	.14−	12.28	1.30	8.49	3.42	′IV	5	4	(4)5	1′	′3	1(2)	2
42	.38	.0	.45	.14+	9.36	1.11	8.77	3.70	IV	5	′4	4(5)	1(2)	3	1(2)	2
43	.37	1.33	1.23	.14−	3.77	1.38	2.31	2.77	IV	7	3	(4)5	2	′3	2	2

General result of the classification.—All but the three most salic rocks come within the range of two classes; that is, in Class III or the adjacent halves of Classes II and IV.

As to the relation of feldspar to quartz or lenads, determining orders in Classes II and III and grads in Class IV, one is quardofelic and 36 are perfelic. Of the latter, two are transitional to the quardofelic and three to the lendofelic order. Three are lendofelic, one of them transitional to perfelic, and three of the basic rocks are still richer in lenads. It is interesting to note that the rocks richest in normative quartz are mostly near the center of Class III.

The strong position of alkali feldspar and lenads as compared with anorthite is brought out strikingly in the symbols. But 11 rocks are docalcic and none percalcic, while four are peralkalic.

The dominance of sodic over potassic silicates is most strongly emphasized in the symbols, which indicate that 32 rocks are dosodic, only one of them being transitional to the sodipotassic subrang, while seven are transitional to the persodic divisions and 11 are persodic. This is the most persistent characteristic brought out by the normative analysis.

The ratio $\frac{P+O}{M}$ is one of the most irregular and is very directly affected by analytical errors, if such there are, in the determination of Fe_2O_3 and FeO. High Fe_2O_3 increases the magnetite or hematite, and thus has marked effect on this ratio. The great majority of the norms are dopolic, and most of the polmitic ones belong in Class II.

The low amount of normative olivine causes a great many rocks to fall in the perpyric division, while another large group is dopyric, and the pyrolic rocks are almost restricted to Class IV. Only three rocks are domolic.

The ratio for $\frac{(MgFe)O}{CaO''}$ is one of the least variable, 35 out of 42 rocks in Classes II, III, and IV yielding domiric norms, while five are permiric and only two calcimiric.

In the relation of magnesia to ferrous iron, there is a general dominance of magnesia, which increases in relative amount from Class II to Class IV, all the latter rocks being domagnesic, while most of the former are magnesiferrous or doferrous.

Analytical errors doubtless affect some of the ratios, but the general characters of the group of rocks analyzed must be correctly expressed in the symbols and stand out at a glance with great clearness.

Quantitative names.—A striking feature of the table of quantitative names is the predominance of compound names. This arises from the fact that a large majority of all rocks are transitional in some one of the four or five factors involved in the classification as far as subrang. Many are transitional in more than one respect, and were it practicable such rocks should bear more than two parts in the compound name expressing their classification. But if symbols expressing transitional character are used, the full compound term is not necessary. It is desirable, however, as my own experience indicates, to use the simple term only for the rock that has no transitional relations.

The disadvantage of a long name is self-evident, but it seems to me small compared with the advantage of the greater accuracy of characterization which is possible with the compound. Naturally, this can not be carried too far. Compound names are often recognized as desirable in the mineralogical system, and manifestly must come into frequent use if the names of that system are really defined, with bounds.

The relations of the various rocks belonging to camptonose, ornose, and auvergnose are pretty clearly indicated by the names of the table, but still more effectively by the symbols. It should be remembered that the last name of a compound is that of the subrang to which a given rock strictly belongs, and that the first name indicates transitional relations which may exist either in subrang, rang, order, or class.

Groups under the quantitative system.—When the data brought together in the table of ratios, symbols, and names are reviewed the chemical characteristics of the analyzed rocks, as interpreted by the normative calculations, are clearly brought out. The largest group of rocks of closely allied normative composition embraces those, 18 in number, belonging to auvergnose

(8), camptonose (6), and ornose (4). Considering first the salic molecules, through which this classification as far as subrang is reached, we may place these rocks either in the alkalicalcic rang camptonase or the docalcic rang auvergnase. The ratios show that 8 out of the 10 rocks falling in camptonase belong in the more calcic half and that 7 out of 8 in auvergnase come in its less calcic half. That means that 15 rocks of these adjacent rangs fall within a range equal to that of a rang.

The 18 rocks of this group are all dosodic or persodic and fall, in fact, within a range equal to that of a full subrang.

As to the femic constituents there is also a close correspondence between most of the rocks of this group. Twelve fall in the dopolic grad, five others are in the narrow transitional zones on either side, and one is perpolic.

The ratios of pyroxene to olivine bring 12 of these rocks in the perpyric section, five in the dopyric division, two of these being transitional to perpyric, and but one is pyrolic.

That magnesia and iron strongly dominate over lime in the femic molecules of this group is shown by the fact that 17 out of 18 rocks belong in the domiric subgrad, while the remaining one is permiric.

The relation of magnesia to iron is shown by the reference of 12 of these rocks to the adjacent transitional zones, while five are strongly domagnesic and but one is markedly doferrous.

The next most important group of the analyzed rocks comes in Class II and represents the dosalic lavas corresponding to camptonose in being alkalicalcic and dosodic. Five rocks fall in subrang andose (II.5.3.4) and three others are transitional to it. This is not so homogeneous a group as the larger one just discussed. But two rocks belong in the central division of andose. Two are in the transitional zone to the percalcic subrang beerbachose, corresponding to ornose. Three are transitional as regards class, being very near camptonose. One is transitional to the lendofelic subrang salemose (II.6.3.4).

The rocks belonging in or adjacent to andose vary considerably in their femic constituents, as the ratios and symbols show. They represent in the main a gradation from the more femic camptonose to the more salic akerose.

Akerose, the domalkalic subrang adjacent to andose, is represented by three rocks, while two others are transitional to it. Kilauose, the corresponding subrang of Class III, has the same representation. These are the domalkalic rocks and all retain the dosodic character. One akerose is transitional to the persalic larvikose.

The rocks of Class IV are similar in their femic characters, but differ notably in the salic constituents, two being peralkalic and four docalcic. The peralkalic rocks are also perlenic.

DISTRIBUTION AND ASSOCIATION OF HAWAIIAN ROCKS.

IN THE HAWAIIAN GROUP.

General distribution.—It is evident from the statements of the first part of this paper that each of the larger islands contains several kinds of rocks showing important differences in both chemical and mineral composition. The converse proposition is also true, that several kinds of rocks are known in all or nearly all the larger islands. But our knowledge concerning all the centers of eruption is so meager that we may well assume that nearly all the varieties described, and perhaps some others, actually occur on each of the principal islands.

From the accompanying table the reader may quickly see the facts of known distribution for the entire Hawaiian group. Basaltic lavas of several varieties are the most common, but, as appears in further discussion of the rocks thus far analyzed, there is a great range in the composition of the basalts and we do not yet know to what extent the basalts of individual centers have peculiarities of their own. One notable apparent limitation is that of the bronzite basalts, which are especially abundant in Oahu, at both of the great centers, and are at least rare in other islands. The melilite-nephelite basalts have been found on three islands and may well be

present on all, among the products of recent and subsidiary eruptions. Possibly that stage of differentiation and eruption which these rocks represent has not yet been reached on Hawaii, unless perhaps in Kohala, the oldest and least-known center. Not much attention has been paid to the products of the minor and recent eruptions of Kauai, Oahu, and other extinct centers, but we can reasonably assume from general experience that they are, as a rule, notably more mafic or more felsic than the lavas of older eruptions. The discovery in other islands of a variety equal to that occurring in the vicinity of Honolulu may plausibly be expected.

Felsic lavas which may be considered as complementary to the highly mafic lavas of Oahu and Kauai have not yet been found on those islands. The trachytes of Puu Waawaa, on Hawaii, and of Lahaina, on Maui, however, represent in a general way such felsic magmas, and the occurrence of nephelite-melilite basalt with the trachyte of Lahaina indicates the genetic connection.

Xenoliths of peridotite and pyroxenite are reported from Kauai, Oahu, Molokai, and Hawaii and doubtless occur in other places.

Distribution of rocks in Hawaiian Islands.

	Soda trachyte.	Oligoclase rocks.	Trachydolerite.	Olivine-poor basalts.	Bronzite basalts.	Normal basalts.
Lesser islands						Laysan Neckar (Möhle).
Kauai		Kauaiite		Rare? Recent?.		Common.
Oahu				Recent?	Common	Rare?
Molokai				(Möhle)		Common (Möhle).
Maui	Lahaina		Haleakala	(Möhle)		West Maui (Möhle).
Hawaii	Puu Waawaa.	Kohalaite	Mauna Kea.	Kilauea, Kohala (Cohen).		Common.

	Picritic basalt.	Limburgite.	Nephelite basalt.	Nephelite-melilite basalt.	Peridotitic xenoliths.
Kauai		Probably rare		One occurrence	In limburgite.
Oahu			Several occurrences.	Several occurrences.	Salt Lake craters.
Molokai					
Maui	Haleakala			Lahaina (Möhle)	
Hawaii	Mauna Loa, Kilauea.				Mauna Kea, Hualalai.

Lack of information concerning rocks of some islands.—The rocks of islands not mentioned in the table of distribution have not been identified by any petrographer. But there is no reason to question the general correctness of the term basalt, which is usually applied to these rocks where they have received casual mention. It is rather curious that three islands in the main group have received practically no attention from geologists. Lanai and Kahoolawe, situated to the west of Maui and visible from it, the former 139 square miles in extent and 3,400 feet in elevation, the latter covering 69 square miles and rising 1,472 feet above the sea, receive bare mention by Dana[1] and a brief paragraph each by Hitchcock.[2] The lavas of Niihau, which lies but 15 miles southwest of Kauai, is 97 square miles in extent, and reaches 1,300 feet above the sea, are likewise without any positive identification. Nihoa, or Bird Island, situated 300 miles west-northwest of Kauai, is described by Bishop[3] as embracing about 250 acres, with two summits each nearly 900 feet in elevation. While Bishop considers the island a remnant of a large volcano and reports 40 or 50 dikes observed during a brief examination, no description of the rocks has been given.

Associated lavas of Kilauea.—It is only for Kilauea that the analytical data suffice to show the prevalent character of the associated magmas at any one center for a considerable period.

[1] Characteristics of volcanoes, p. 27, New York, 1890. [2] Hawaii and its volcanoes, 2d ed., p. 45, Honolulu, 1911. [3] Idem, p. 9.

Even at Kilauea we know little concerning lavas that are older than those exposed in the walls of the caldera, which form in fact merely the uppermost part of the volcano.

Twenty-one analyses of Kilauean lavas have been given in the table. Eleven of these represent rocks from the active center of Halemaumau, nine rocks exposed in the walls of the main caldera, and one a fragment in tuff from the crest of the rim.

The 11 lavas of Halemaumau represent a number of eruptions, from the current one back as far as 1843, at least. All are very similar in composition; in fact, 9 of them belong to the camptonose-ornose-auvergnose group (hereafter called C.-O.-A.), which has been referred to (p. 58) as the most notable rock group of the islands. Seven of these nine rocks are within a single division, having the scope of a subrang, about the center point of the C.-O.-A. group, and the other two are only a trifle too rich in orthoclase to come within this division. Of the two rocks not belonging to the C.-O.-A. group, one is a "Pele's hair," analyzed by Cohen, which is the domalkalic kilauose, adjacent to camptonose, and the other is like the C.-O.-A. group except in its high normative quartz, which brings it in order 4, vaalare.

Quartz appears in six norms of Halemaumau lavas (ranging from 0.8 to 8.46 per cent), olivine in five (3.6 to 8.3 per cent), and nephelite in one (2.6 per cent). It appears, then, that the lavas of Halemaumau can not be rich in olivine except with coexistent free silica. As nine of the analyses are so nearly in accord, it seems worth while to strike an average for them as representing the lavas of Halemaumau of the last 70 years fairly well. The two analyses not used in obtaining this average, Nos. 34 and 14, by Cohen and Phillips, respectively, are apparently less trustworthy. In neither is TiO_2, P_2O_5, or MnO determined. Both have normative quartz, the latter containing 8.46 per cent. The former has very low alumina. The average of the other nine analyses of the C.-O.-A. group is as follows:

Average of nine Halemaumau lavas.

Analysis.		Norm.	
SiO_2	50.18	Orthoclase	4.45
Al_2O_3	14.12	Albite	22.53
Fe_2O_3	3.04	Anorthite	24.19
FeO	10.45	Diopside	22.42
MgO	6.42	Hypersthene	17.02
CaO	10.67	Olivine	1.48
Na_2O	2.69	Magnetite	4.41
K_2O	.75	Ilmenite	3.34
TiO_2	1.75	Apatite	.51
P_2O_5	.21		100.35
MnO	.19		
	100.47		

A rock of this composition would be camptonose-auvergnose, with symbol III.5.(3)4.4′. Such a magma must yield an almost olivine-free holocrystalline rock if the available silica is all utilized in forming metasilicates in preference to orthosilicates, among the femic molecules, as is supposed to be the normal condition in magmatic solutions. If the two analyses omitted had been included, SiO_2 would have been increased and Al_2O_3 decreased in the average and quartz would have replaced olivine in the norm.

The table contains eight analyses, by Silvestri, of lavas from the caldera walls. Such flows must of course antedate the formation of the caldera and thus belong to a period of eruption considerably older than the historic eruptions of Halemaumau. Now, it happens that although the analyses of these older lavas are apparently very similar to those of lavas of the later epoch, the normative study reveals certain rather characteristic differences which will be discussed. As all the analyses of the older rocks were made by Silvestri, one might suspect that the difference is due to analytical methods were it not that Silvestri's two analyses of Halemaumau lavas agree with others of rocks from that center.

The recent lavas of Halemaumau contain on the average 2.14 per cent more SiO_2 than the older rocks. Only one of the recent lavas has as low SiO_2 as the average of the older ones, and none of the older rocks contains as much SiO_2 as the average of the recent lavas. This relation has its converse in the alumina contents of the two groups. The recent lavas have an average of 13.81 per cent and the older ones of 16 per cent of Al_2O_3. But one of the younger lavas has more than 16 per cent of Al_2O_3 and not one of the older rocks carries less than 13.97 per cent. The exceptional recent lavas, low in SiO_2 and high in Al_2O_3, are not the ones analyzed by Silvestri.

These analytical differences find striking expression in the norms. The lavas of Halemaumau, with their higher silica and lower alumina, have normative quartz or low olivine, with lower feldspars and lenads. The older rocks, with less silica and more alumina, have more feldspar, lenad, and olivine, and but one has normative quartz.

These differences find still further expression in the quantitative classification of the rocks. The norms of the older lavas of the caldera wall are so rich in feldspar and nephelite, by virtue of their high alumina, that with one exception they belong in Class II or (in three cases) in the narrow transitional limits of Class III. The average of the ratio $\frac{Sal}{Fem}$ for the Halemaumau lavas is 1:15, for the older rocks 1:54, and these figures, striking as they are, probably fail to emphasize this difference sufficiently, for one exceptional rock in each group is open to suspicion. The most salic of the Halemaumau rocks is a stalagmite from a lava cave (No. 14) analyzed by Phillips. It is natural to suppose that the drippings in this cavern were richer in SiO_2 than the average of the flow. If this analysis, which is not of high grade in other respects, is excluded the average $\frac{Sal}{Fem}$ for the recent lavas is lowered to 1:10.

The exceptional rock for the older group is the "kilaueite' of Silvestri, an aphanitic saccharoidal basalt which is classified as auvergnose and belongs in the C.-O.-A. group embracing most of the Halemaumau lavas. As Silvestri's specimens were not collected by a geologist the suspicion may be entertained that this kilaueite represents a flow from Halemaumau that reached the foot of the caldera wall. If this rock is stricken from the list of older lavas the average ratio $\frac{Sal}{Fem}$ for them becomes 1:64.

The classification of the older lavas is as follows:

9. Kilauose-akerose ..... II(III).5(6).3.4 (olivine 9.3).
11. Limburgose-salemose ..... II(III).6.3.(3)4 (olivine 6.0).
12. Camptonose-andose ..... II(III).5.3.4 (olivine 13.7).
13. Kilauose-akerose ..... II(III).5.2.4 (olivine 9.1).
15. Monchiquose-kilauose ..... (II)III.5(6).2'.4 (olivine 10.0).
16. Andose-camptonose ..... (II)III.5.3.4' (olivine 3.1).
17. Auvergnose-camptonose ..... (II)III.5.3(4).4 (olivine 2.7).
20. Auvergnose ..... III 5.4.4–5.

If the last-named rock, the kilaueite, is omitted, the older lavas of Kilauea are shown by the data given to form a group notably different from the lavas of Halemaumau. The normative olivine content, which is doubtless less, if anything, than the modal, makes them apparently typical basalts, though high in feldspars. True, one of them, No. 6, is called "andesite augitica" by Silvestri, though it has 6 per cent normative olivine.

What may be the significance of this difference between the lavas of different periods of eruption remains to be determined. The rocks considered do not represent the complete range of lavas erupted in these two periods, for Dana found a lava very rich in olivine at the base of Waldrons Ledge, and Daly's gabbro of Uwekahuna is also very highly femic. Then, too, the olivinic lava of 1840, in Puna, was apparently connected with Kilauea. (See p. 43.)

WORLD DISTRIBUTION OF HAWAIIAN MAGMATIC TYPES.

Method of study of distribution.—It is proposed to set forth in this part of the discussion the results of an examination of the occurrence and association in other parts of the world of igneous rocks which are most nearly like the Hawaiian lavas in chemical composition. The rocks selected as analogues of Hawaiian types are by no means identical with them in chemical composition, but they approximate identity more closely than any other rocks that have come to my notice. The analogues have been chosen on the basis of similarity in norms rather than in analyses, as it is through the norm that the significance of the several differences between analyses may best be understood.

The approach to chemical identity between the rocks compared naturally varies somewhat with the number of analyses available for comparison or the abundance of the given variety. But in general the degree of similarity is much greater than that which is commonly considered significant by petrographers discussing relationships in special cases. In fact, most of the similarities to be pointed out are as great as the decided correspondence between different lavas of Halemaumau erupted during the last 60 years.

Many analyses and norms have been copied from Washington's well-known Tables [1] and such norms have generally not been recalculated and no further reference is deemed necessary. I am greatly indebted to Dr. Washington for placing at my disposal a number of his own unpublished analyses of rocks from Sardinia and Pantelleria, as well as numerous calculations of norms made by him from analyses found in recent publications, in the course of preparation for a new edition of his invaluable Tables. The original sources of these analyses are not given.

[1] U. S. Geol. Survey Prof. Paper 14, 1903.

Analogues of Hawaiian lavas.

I.

	1	a	b	c	d	e
SiO_2	61.69	60.05	64.33	62.17	62.15	59.92
Al_2O_3	17.31	19.97	17.52	18.58	20.97	14.30
Fe_2O_3	5.30	4.32	3.06	2.15	1.68	7.50
FeO	.07	1.04	.94	1.05	1.01	.42
MgO	.16	.23	.34	.73	.41	.72
CaO	1.05	.91	.56	1.57	1.56	1.90
Na_2O	7.47	7.69	7.30	7.56	7.88	5.32
K_2O	3.47	3.24	4.28	3.88	3.02	5.77
H_2O+	1.93	1.26	.95	1.63	.....	2.49
H_2O-	.42	.15	.04	.07	1.02	.34
TiO_2	.67	.11	Trace.	Trace.	.14	.87
P_2O_5	.07	.....	Trace.	.11	.58	.58
MnO	.21	.79	.35	Trace.	.....	.06
BaO	.07	.....	.....	.....	.....	.05
Inclusive	[a] .21	[b] .28	.....	.....	.....	.17
Sum	100.10	100.04	99.67	99.50	100.42	100.30
Quartz	2.88	1.3	3.9	.6	2.44	5.40
Orthoclase	20.57	18.9	25.6	22.8	17.77	34.47
Albite	62.88	64.5	61.3	63.8	66.55	41.39
Anorthite	3.61	4.4	2.8	5.3	4.17	.....
Corundum	.....	2.3	.....	.....	3.26	.....
Zircon	0.18	.....	.....	.....	.....	.....
Acmite	.....	.....	.....	.....	.....	2.77
Diopside	.43	.....	.....	2.0	.....	3.67
Hypersthene	.20	.6	.9	1.1	1.13	.10
Magnetite	.....	3.2	3.0	3.2	2.55	.....
Hematite	5.28	2.0	1.0	.....	.....	6.56
Ilmenite	.61	.....	.....	.....	.30	1.06
Apatite	.....	.....	.....	.....	1.34	1.34
Titanite	.98	.....	.....	.....	.....	.78
	97.62	97.2	98.5	98.8	99.51	97.54

[a] ZrO_2, 0.16; S, 0.02; SrO, 0.03. [b] Cl, 0.28.

1. Soda trachyte, nordmarkose, I′.5.1′.4. Cone near Lahaina, west coast of Maui (p. 27).
a. Biotite tinguaite (Eakle). Gales Point, Essex County, Mass.
b. Acmite trachyte (Wolff and Tarr). Sixteenmile Creek, Crazy Mountains, Mont.
c. Acmite trachyte (Wolff and Tarr). Northern part of Crazy Mountains, Mont.
d. Trachyte (Schneiderhöhn), nordmarkose, I.5.1.4. Haarweiden, Westerwald, Hesse-Nassau.
e. Trachyte (Washington), ilmenose, ′II.5.1.3. Monte Muradu, Macomer, Sardinia.

Analogues of Hawaiian lavas—Continued.

I—Continued.

	2	a	b	c	d	e	f
SiO_2	62.19	64.28	62.70	63.20	63.24	60.50	63.43
Al_2O_3	17.43	15.97	16.40	17.45	17.98	18.20	16.31
Fe_2O_3	1.65	2.91	3.34	3.60	2.67	1.34	2.04
FeO	2.64	3.18	2.35	.....	.85	1.89	3.14
MgO	.40	.03	.79	.75	.63	1.18	.78
CaO	.86	.85	.95	1.40	.93	1.75	1.70
Na_2O	8.28	7.28	7.13	6.90	6.27	7.25	6.71
K_2O	5.03	5.07	5.25	5.88	5.47	4.45	4.31
H_2O+	.39	.20	.70	.50	.80	2.30	.18
H_2O-	.14		.....	.....	.37		.26
TiO_2	.37	.50	.92	.46	.38	.92	1.19
CO_2	.02	.....	.....	.....	.....	.....	None.
P_2O_5	.14	.08	.....	.....	.22	.....	.20
MnO	.32	.....	.....	.....	.04	.....	.04
BaO	.03	.....	.....	.....	.25	.....	.05
Inclusive	.....	.12	.....	.....	.03	.....	.11
Sum	99.93	100.33	100.53	100.14	100.14	99.78	100.45
Quartz	.....	2.0	.....	.....	2.8	.....	3.9
Orthoclase	29.47	30.0	31.1	35.0	32.8	26.7	25.6
Albite	51.87	53.4	55.0	48.2	52.9	54.3	56.6
Anorthite	.....	.....	.....	.....	4.4	3.6	1.7
Nephelite	5.40	.....	.....	5.4	.....	3.8	.....
Noselite	.61	.....	.....	.....	.....	.....	.....
Acmite	4.62	6.9	4.6	1.4	.....	.....	.....
Diopside	2.88	3.7	3.9	5.9	.....	4.0	4.8
Hypersthene	.....	2.8	.....	.....	1.6	.....	1.6
Olivine	3.24	.....	1.1	2.4	.....	1.5	.....
Magnetite	.....	.7	2.6	.....	1.6	1.9	3.0
Hematite	.....	.....	.....	.....	1.6	.....	.....
Ilmenite	.76	.9	1.7	.9	.8	1.7	2.3
Apatite	.34	.....	.....	.....	.....	.....	.3
	99.19	100.4	100.0	99.2	98.5	97.5	99.8

2. Trachyte obsidian, nordmarkose-umptekose, (I)II.5′.1.4. Puu Waawaa, island of Hawaii (p. 35).

a. Glaucophane-sölvsbergite (Washington), ilmenose-umptekose, (I)II.5.1.(3)4. Andrews Point, Cape Ann, Essex County, Mass.

b. Hornblende sölvsbergite (Brögger), ilmenose-umptekose, (I)II.5.1.(3)4. Laugendal, Christiania district, Norway.

c. Nordmarkite (Brögger), phlegrose-nordmarkose, I(II).5′.1.(3)4. Tonsenas, near Christiania, Norway.

d. Biotite trachyte (Hague and Jaggar), phlegrose-nordmarkose, I.5.1.(3)4. Dike Mountain, Yellowstone National Park.

e. Phonolite (Lacroix), nordmarkose, I′.5.1′.4. Vaïrao, Tahiti.

f. Trachyte (Washington), umptekose-nordmarkose, I(II).5.1.4. Montagne Grande, Pantelleria.

Analogues of Hawaiian lavas—Continued.

II.

	3	a	b	c	d	e	f	g
SiO_2	58.06	56.80	56.99	58.48	60.44	59.95	60.98	57.59
Al_2O_3	18.21	17.81	17.62	19.24	16.67	17.47	19.09	22.38
Fe_2O_3	4.87	1.40	2.65	5.75	2.31	2.59	1.76	3.09
FeO	2.01	4.84	3.75	n. d.	3.09	3.15	1.15	.78
MgO	1.59	1.34	2.79	.99	2.18	1.18	.65	2.34
CaO	3.29	5.21	4.40	5.02	4.22	3.25	3.67	3.23
Na_2O	6.12	6.15	5.95	5.52	5.18	6.38	6.70	6.11
K_2O	2.75	2.81	2.88	3.06	2.71	2.98	3.53	3.40
H_2O+	.....	1.60	.60	.47	1.43	1.04	.44	.70
H_2O-	.....					.....	.48	
TiO_2	1.88	1.61	.60	.96	.60	1.57	.36	.....
CO_2	.....	.....	.....	.....	.48	.....	.52	.....
P_2O_5	.65	.45	1.05	.....	.29	.02	.10	.....
MnO	.36	.....	.19	Trace.	.13	.....	.15	.....
BaO	.....	.....	.....	.....	.12	.....	.43	.....
Inclusive	[a].20	.....	.....	.....	SrO. 11	.....	SrO. 28	.....
Sum	99.99	100.02	99.47	99.41	99.96	99.88	100.29	99.62
Quartz	4.08	.....	.....	.7	8.82	3.42	1.62	.....
Orthoclase	16.68	16.7	17.24	18.3	16.12	17.79	20.57	20.0
Albite	51.35	50.8	50.30	45.6	43.49	53.97	56.59	51.9
Anorthite	12.79	12.8	12.79	19.2	14.46	10.01	11.68	16.1
Nephelite	.....	.6	.....	.....	.....	.....	.....	.....
Corundum	.41	.....	.....	.....	.....	.....	.....	2.8
Diopside	4.00	8.2	2.26	5.0	1.57	4.91	3.83	.....
Hypersthene	.....	.....	6.71	7.9	7.64	1.70	.....	.....
Olivine	.....	3.2	2.42	.....	.....	.....	.....	4.1
Magnetite	2.09	2.1	3.71	.....	3.25	3.71	2.55	2.6
Hematite	3.36	.....	.....	.....	.....	.....	.....	1.3
Ilmenite	3.65	3.0	1.22	1.8	1.22	3.04	.76	.....
Apatite	1.34	1.2	2.17	.....	.67	.....	.24	.....
Rest	.20	1.6	.60	.....	.....	.....	2.02	.....
	99.95	100.2	99.42	98.5	97.24	98.55	99.86	98.8

[a] CuO, 0.10; SO_3, 0.05; S, 0.05.

3. Feldspathic lava (Lyons), larvikose-akerose, (I)II.5.2.4. Kohala Mountain, near Waimea, island of Hawaii.

a. Leeuwfonteinite (Brouwer), akerose, 'II.5.2.4. Leeuwfontein, Pretoria district, Transvaal.

b. Natron-minette (Hackmann), akerose, 'II.5.2.4. Autionsaari, Tavajärvi, Kuusamo, Finland.

c. Akerite (Brögger), andose-akerose, (I)II.5.2(3).4. Ramnäs, Christiania region, Norway.

d. Quartz monzonite porphyry (Cross), dacose-akerose, (I)II.(4)5.2'.4. Dike, Deadwood Gulch, La Plata Mountains, Colo.

e. Akerite (Lacroix), larvikose-akerose, (I)II.5.2.4. Bras Rouge, Cilaos, Reunion Island.

f. Monzonite porphyry (Cross), larvikose, I'.5.2.4. Dike, north spur of Mount Pennell, Henry Mountains, Utah.

g. Augite syenite (Brögger), larvikose, I'.5.2.4. Fagerheimaasen, Notterö, Norway.

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Analogues of Hawaiian lavas—Continued.

III.

	a	b	c	d	e	f	g	h
SiO_2	52.67	49.24	53.04	49.84	51.26	49.55	52.83	55.07
Al_2O_3	15.35	15.84	17.34	17.78	16.74	17.78	17.67	19.57
Fe_2O_3	3.82	6.09	2.12	5.86	2.92	4.65	7.50	3.38
FeO	5.42	7.18	6.96	2.62	7.11	5.89	1.68	3.42
MgO	4.40	3.02	2.49	3.02	2.80	2.49	2.47	1.68
CaO	5.91	5.26	5.86	7.35	6.61	7.01	7.35	5.56
Na_2O	4.50	5.21	5.61	5.20	5.86	6.12	6.61	7.10
K_2O	2.68	2.10	3.00	3.04	2.25	2.29	2.52	3.34
H_2O+	.37	1.61	.37	2.02	.42	.34	2.32	.38
H_2O-	.14	1.08	.....	.34	.26	.29		.....
TiO_2	4.04	1.84	2.12	1.43	2.57	2.09	.....	.....
CO_2	.....	.....	.....	.52	Trace.	None.	.....	.....
P_2O_5	.75	1.47	.83	.76	.81	1.10	.....	.....
MnO	.....	.29	.....	.21	.23	.28	.....	.....
BaO	.....	.09	.....	.22	.10	.05	.....	.....
Inclusive	.....	[a].21	.....	[b].21	[c].09	[d].13	.....	.....
Sum	100.05	100.46	99.74	100.45	100.03	100.06	100.95	99.50
Quartz	1.20	.....	.....	.....	.....	.....	.....	.....
Orthoclase	16.12	12.23	17.79	17.79	12.79	13.34	15.0	19.5
Albite	38.25	44.01	39.30	32.49	38.25	34.58	35.6	36.2
Anorthite	13.34	13.62	13.34	16.40	12.79	15.01	10.8	12.0
Nephelite	.....	.....	4.26	6.25	6.25	9.09	11.1	12.8
Diopside	8.64	2.97	8.57	9.94	12.40	10.42	13.4	13.1
Hypersthene	7.00	2.49	.....	.....	.....	.....	3.5	.....
Olivine	.....	6.36	6.99	2.03	5.69	3.80	.....	.8
Magnetite	5.57	9.05	3.02	4.87	4.18	6.73	5.3	4.9
Hematite	.....	.....	.....	2.40	.....	.....	3.8	.....
Ilmenite	7.75	3.50	4.10	2.74	4.86	3.95	.....	.....
Apatite	1.68	3.36	2.02	1.81	2.02	2.69	.....	.....
	99.55	97.59	99.39	96.72	99.23	99.61	98.5	99.3

[a] F, 0.18; S, 0.03.
[b] SrO, 0.18; ZrO_2, 0.03.
[c] SrO, 0.09.
[d] ZrO_2, 0.01; FeS_2, 0.03; SrO, 0.08, V_2O_3, 0.015.

a. Basalt (Washington), akerose, II.5.2′.4. Mount San Mateo, Ploaghe, Sardinia.
b. Mugearite (Harker), akerose, II.5.2′.4. Island of Skye, Scotland.
c. Olivine trachyandesite (Lacroix), akerose, II.5.2.4. Bellouve, Reunion Island.
d. Trachydolerite (Graton), akerose, II.5′.2′.4. Bull Cliff, Cripple Creek district, Colo.
6. Trachyandesite (Cross), akerose, II.5′.3.4. Vieira's ranch, south of Kaupo Gap, Haleakala, Maui.
4. Trachyandesite (Cross), akerose-essexose, II.(5)6.2.4. White Hill, crater of Haleakala, Maui.
e. Carmeloite (Lawson), akerose-essexose, II.(5)6.2.4. Sunium Point, Carmelo Bay, Cal.
f. Rhombenporphyr (Brögger), essexose, II.6′.2.4. Stoksund, Norway.

Analogues of Hawaiian lavas—Continued.

IV.

	c	d	e	f	5	7	g	h	i	j
SiO_2	48.67	48.63	47.61	52.18	50.92	49.73	52.92	56.47	54.70	54.19
Al_2O_3	16.88	17.01	17.47	18.19	17 59	16.39	17.70	15.33	18.05	16.28
Fe_2O_3	4.98	2.92	3.44	3.31	3.80	7.58	3.16	2.54	3.63	5.08
FeO	6.37	8.85	8.78	4.36	6.69	3.98	4.48	4.53	3.31	3.46
MgO	4.62	3.87	2.49	4.69	3.90	4.06	4.34	5.08	3.90	2.98
CaO	8.63	7.90	7.04	5.61	6.97	7.17	5.90	6.93	6.36	6.34
Na_2O	3.85	3.98	4.49	4.58	4.28	4.12	4.08	3.81	4.08	4.05
K_2O	1.26	1.76	1.60	1.88	1.86	1.93	2.24	1.66	1.97	1.98
H_2O+	.32	.22	3.71	2.00	.79	.81	1.42	1.65	3.28	3.67
H_2O-	.02	.....	.84	.75	.35	.54	.....	.....	.....	.....
TiO_2	2.12	4.02	.87	.99	2.55	3.05	.94	.99	1.09	1.56
CO_2	.....	.....	.28	None.	.....	None.	.....	.....	.....	.07
P_2O_5	1.85	.77	1.10	.29	.40	.84	.18	.54	Trace.	.43
MnO	.....	.....	.13	.14	.20	.23	Trace.	.18	.....	.....
BaO	.....	.....	.....	.11	.....	.03	.....	.....	.....	.....
Inclusive	.....	.....	.....	.06	.....	.07	.09	.....	.13	.14
Sum	99.57	99.93	99.85	100.04	100.30	100.53	100.45	99.71	100.50	100.23
Quartz	.....	.....	.....	.....	.....	1.7	3.5	6.8	4.7	8.0
Orthoclase	10.0	10.6	9.5	11.1	11.1	11.1	13.9	10.0	11.7	11.7
Albite	32.5	34.1	36.7	38.8	36.2	34.6	34.6	32.0	34.6	34.1
Anorthite	23.9	22.2	22.5	23.4	23.4	20.9	23.1	22.5	25.0	20.6
Nephelite	.....	.....	.8	.....	.....	.....	.....	.....	.....	.....
Diopside	5.6	10.0	4.2	7.2	6.8	7.1	5.0	6.8	5.4	6.5
Hypersthene	10.3	1.1	.....	3.8	7.3	6.9	12.0	14.0	8.6	4.5
Olivine	2.0	8.0	12.2	5.8	3.2	.....	.....	.....	.....	.....
Magnetite	7.2	4.2	4.9	4.9	5.6	4.6	4.6	3.5	5.1	7.4
Hematite	.....	.....	.....	.....	.....	4.5	.....	.....	.....	.....
Ilmenite	3.9	7.6	1.7	1.8	4.9	5.8	1.7	1.8	2.0	2.9
Apatite	4.4	1.7	2.7	.....	1.0	2.0	.....	1.2	.....	1.0
	99.8	99.5	95.3	96.8	99.5	99.2	98.4	98.5	97.1	96.7

c. Norite (Pirsson), camptonose-andose, II(III).5.3.4. Slide Brook, Waterville, N. H.

d. Basalt (Lacroix), andose, II.5.3.4. Avirons, Reunion Island.

e. Porphyrite (Sheight and Finlayson), andose, II.5.3.4. Carnley Harbor, Auckland Islands.

f. Diabase (Hague and Jaggar), andose. Shoshone Canyon, Yellowstone National Park.

5. Trachydolerite (Daly), andose, II′.5.3.4. Poliahu Cone, near summit of Mauna Kea, Hawaii.

7. Andesitic basalt (Daly), andose, II.5.3.4. At 11,000 feet S. 75° E. of summit of Mauna Kea, Hawaii.

g. Hornblende andesite (Iddings), andose. Sepulcher Mountain, Yellowstone National Park.

h. Pyroxene andesite (Iddings), andose. Near Dunraven Peak, Yellowstone National Park.

i. Porphyrite (Lossen), andose. Heichweiler, St. Wendel, Harz Mountains, Germany.

j. Basalt (Lossen), andose. Idarthal, St. Wendel, Harz Mountains, Germany.

Analogues of Hawaiian lavas—Continued.

V.

	a	b	c	d	e	8	10	f	g	h
SiO_2	55.08	50.33	52.79	50.45	53.31	46.30	49.01	50.86	52.99	51.98
Al_2O_3	18.93	19.97	16.45	18.90	20.05	17.95	16.29	15.72	16.71	17.20
Fe_2O_3	2.02	2.81	2.74	7.73	2.18	6.21	7.61	9.77	3.80	8.22
FeO	5.56	6.23	6.44	2.61	3.37	6.79	4.89	2.48	3.55	2.00
MgO	5.17	3.24	5.56	5.41	3.33	3.67	3.62	3.55	6.95	5.41
CaO	8.40	8.03	6.51	9.00	8.65	8.17	9.79	10.52	8.49	8.17
Na_2O	4.23	4.30	3.64	3.92	4.17	3.92	3.82	3.89	3.56	3.84
K_2O	.74	1.19	1.21	1.05	1.30	.89	.80	.90	1.29	.90
H_2O+	.29	.99	1.02	.10	2.02	.....	.....	2.53	.59	.62
H_2O-	.....	.87	.21	.18	.....	.....	.....	.....	.18	.....
TiO_2	.....	1.81	2.64	.27	1.16	5.35	3.93	.....	1.18	.36
CO_2	.....	.....	.....	.....	.06	.....	.....	.....	.....	.....
P_2O_5	.....	.17	.39	.52	.18	.53	.49	.....	.42	.99
MnO	.....	.17	.06	.....	.....	.26	.27	.....	.....	.....
BaO	.....	.06	.....	.....	.....	.....	.....	.....	.07	.....
Inclusive	.....	.....	.18	.....	.20	.28	.32	.....	.14	.....
Sum	100.42	100.17	99.84	100.14	99.98	100.32	100.84	100.22	99.92	99.69
Quartz	.6	.....	4.5	.2	1.6	.3	3.1	3.2	2.2	4.8
Orthoclase	.44	7.2	7.2	6.1	7.8	5.0	4.5	5.6	7.8	5.6
Albite	35.6	36.1	30.9	33.0	35.6	30.0	32.0	33.0	29.9	32.5
Anorthite	30.3	31.7	24.7	30.9	31.7	28.9	25.3	22.5	25.9	27.0
Diopside	9.2	5.2	3.8	8.0	9.0	6.3	15.8	19.3	11.1	5.4
Hypersthene	16.9	4.6	17.2	9.8	6.7	6.3	1.8	2.0	13.7	11.0
Olivine	.....	5.2	.....	.....	.....	.....	.....	.....	.....	.....
Magnetite	3.0	4.2	3.9	7.7	3.2	6.7	5.3	8.1	6.6	6.5
Hematite	.....	.....	.....	2.4	.....	1.6	4.0	4.2	.....	3.7
Ilmenite	.....	3.5	5.0	.5	2.2	10.0	7.5	.....	2.3	.....
Apatite	.....	.7	1.0	1.3	.....	1.2	1.2	.....	1.0	2.4
	100.0	98.3	98.2	99.9	97.8	99.3	100.5	97.9	100.5	98.9

a. Andesite-basalt (Diller), beerbachose. Delta, Shasta County, Cal.
b. Olivine dolerite (Harker), andose, II.5.3′.4′. Druim na Criche, near Portree, island of Skye.
c. Basalt (Washington), andose. Uras, Monte Arci, Sardinia.
d. Hypersthene diorite (Chelius), beerbachose-andose, II.5.3(4).4(5). Lichtenberg, Odenwald, Hesse, Germany.
e. Dolerite (Lossen), andose. Sattel, Niederkirchen, Nahethal, Rhenish Prussia.
8. Highly feldspathic lava (Lyons), beerbachose-andose, II′.5.3.4(5). Waianae Mountains, Oahu.
10. Porphyritic lava (Lyons), andose-beerbachose, II(III).5.3′.(4)5. Kohala Mountain, northern district of Hawaii.
f. Gabbro (Wadsworth), andose. Near Baptism River, Minn.
g. Basalt (Patton), andose. Red Cone, Crater Lake, Oreg.
h. Basalt (Hoppe), andose. Cerro de Guadalupe, Puebla, Mexico.

Analogues of Hawaiian lavas—Continued.

VI.

	9	a	b	c	d	11	e	12	f	g	h
SiO_2	48.71	43.94	48.60	45.10	45.67	50.16	44.25	45.61	48.33	48.98	46.45
Al_2O_3	18.87	16.17	17.87	19.30	17.84	17.97	16.27	15.98	16.29	16.88	16.98
Fe_2O_3	3.18	3.96	6.20	1.55	9.54	2.23	1.50	8.25	3.24	3.30	3.94
FeO	8.00	10.06	5.76	8.70	4.04	6.25	10.30	11.60	8.73	7.29	8.57
MgO	4.85	5.05	4.32	5.30	3.85	4.70	6.51	3.75	5.70	5.27	5.94
CaO	9.87	9.59	9.11	9.81	9.78	11.85	10.14	6.42	8.50	8.86	7.64
Na_2O	4.15	2.93	4.66	4.32	3.88	3.50	3.24	3.50	3.59	3.39	3.50
K_2O	1.52	1.51	2.06	1.58	1.44	2.80	1.98	1.82	1.49	2.11	1.43
H_2O+	.....	1.42	1.78	.75	1.97	.90	2.40	.27	} .82	{ .52	.68
H_2O-	.....	.13	.....	.....	.....	.....	.....	.....	}	{ 1.78	.24
TiO_2	1.81	4.13	.....	3.49	1.57	.....	3.65	1.15	2.40	1.28	3.11
CO_2	.....	.09	.....	.....	.....	.....	.....	.....	.....	.06	.41
P_2O_5	Trace.	.69	.....	.57	.....	.....	.63	.72	.79	.30	.51
MnO	Trace.	Trace.	.....	.....	.....	.30	.....	1.20	.11	.31	.48
Inclusive	.....	.....	.....	.....	.....	.....	.....	.....	.....	.08	.....
Sum	100.96	99.67	100.36	100.47	99.58	100.66	100.87	100.27	99.99	100.41	100.88
Orthoclase	8.9	8.9	12.2	9.5	8.3	16.7	11.7	11.1	8.9	12.2	8.3
Albite	22.5	22.0	22.5	17.3	24.8	11.0	11.5	29.3	30.4	28.8	29.3
Anorthite	28.4	26.7	21.7	28.6	27.2	25.0	24.2	22.2	23.9	24.7	26.7
Nephelite	6.8	1.4	9.1	11.1	4.2	9.9	8.5	.....	.....	.....	.....
Diopside	16.8	13.4	18.8	11.1	16.4	27.8	18.4	4.0	11.0	14.6	6.3
Hypersthene	.....	.....	.....	.....	.....	.....	.....	3.7	2.7	.....	2.2
Olivine	9.4	10.5	5.2	12.2	1.4	6.0	13.8	13.7	11.5	9.7	12.7
Magnetite	4.6	5.8	9.0	2.3	8.6	3.3	2.1	12.1	4.6	4.9	5.6
Hematite	.....	.....	.....	.....	3.5	.....	.....	.....	.....	.....	.....
Ilmenite	3.5	7.9	.....	6.7	3.0	.....	7.0	2.2	4.6	2.4	5.9
Apatite	.....	1.7	.....	1.3	.....	.....	1.3	1.7	1.9	.7	1.3
	100.9	98.3	100.5	100.1	97.4	99.7	98.5	100.0	99.5	98.0	98.3

9. Basalt (Silvestri), salemose-andose, II′.5(6).3.4. Wall of caldera, Kilauea.

a. Essexite (Pirsson and Washington), andose-camptonose, (II)III.5.3(4).4. Lockes Hill, Mount Belknap, N. H.

b. Dolerite (Speight), salemose. Dyers Pass, Canterbury, New Zealand.

c. Nephelite gabbro (theralite) (Lacroix), salemose, II′.′6.3.4. Papenoo Valley, Tahiti.

d. Nephelite tephrite (Bücking), andose, II′.5′.3.4. Suchenberg, Rhöngebirge, Germany.

11. Augite andesite (Silvestri), limburgose-salemose, II(III).′6.3.(3)4. Wall of caldera, Kilauea.

e. Basalt (Lacroix), camptonose-limburgose, ′III.(5)6.3.4. Papenoo Valley, Tahiti.

12. Basaltoid (Silvestri), camptonose-andose, II(III).5.3.4. Wall of caldera, Kilauea.

f. Alkali feldspar bearing basaltic bomb (Kozu), camptonose-andose, II(III).5.3.4. Volcano Ondake, Fukae, Goto Islands, Japan.

g. Olivine basalt (Card), andoee, II′.5.3.4. Northeast of St. Georges Head, New South Wales.

h. Basalt (Tyrrell), camptonose-andose, II(III).5.3′.4. Stockiemuir, Kilpatrick Hills, Scotland.

Analogues of Hawaiian lavas—Continued.

VII.

	13	a	15	b	c	d	26	e	f
SiO_2	49.45	52.85	47.63	49.16	49.78	50.15	45.81	44.85	46.52
Al_2O_3	13.97	13.25	15.02	14.17	13.37	15.21	11.90	12.55	10.48
Fe_2O_3	8.10	2.36	8.15	4.62	2.16	1.54	4.62	3.33	4.40
FeO	11.17	8.71	10.40	6.60	7.51	7.32	8.09	5.30	7.79
MgO	1.90	6.84	3.50	7.01	7.61	7.54	5.39	10.24	10.58
CaO	5.92	8.47	6.87	6.45	7.95	7.18	10.67	8.32	9.49
Na_2O	5.05	4.72	4.92	4.61	4.72	4.31	4.28	4.77	3.12
K_2O	1.75	1.53	1.80	2.23	2.37	2.59	1.40	.72	1.55
H_2O+	1.19	.93	.30	4.22	.34	.35	.53	2.01	1.79
H_2O-					.08	.12	.47	.95	
TiO_2		.35	.12	.42	3.11	3.37	4.05	5.07	2.98
P_2O_5	.16	.40	.08		.72	.67	2.20	1.17	.83
MnO	.85		.80				.17	.07	.11
BaO							.04		
Inclusive							.03	.23	.73
Sum	99.51	100.41	99.59	99.49	99.71	100.35	99.65	99.60	100.37
Orthoclase	10.6	8.9	11.1	12.8	13.9	15.6	8.3	4.5	8.9
Albite	38.3	35.1	27.8	29.3	26.7	28.3	29.3	28.3	24.1
Anorthite	10.0	10.6	13.3	11.7	8.3	14.2	9.2	10.6	10.3
Nephelite	2.6	2.6	7.4	5.1	7.1	4.5	3.7	6.5	1.1
Diopside	15.8	23.4	17.5	16.5	21.2	13.3	23.8	17.9	24.6
Olivine	9.1	14.0	10.0	12.4	11.2	13.8	4.8	12.2	14.8
Magnetite	11.8	3.5	11.8	7.5	3.3	2.3	6.7	2.3	6.5
Hematite								1.8	
Ilmenite		.6			5.9	6.4	7.6	9.7	5.7
Apatite	.3	1.0	.3		1.7	1.7	5.0	2.7	1.9
	98.5	99.7	99.2	95.3	99.3	100.1	98.4	96.5	97.9

13. Hornblende basalt (Silvestri), kilauose-akerose, II(III).5.2.4. Wall of caldera, Kilauea.
a. Basalt (Hoppe), kilauose. Cerro San Miguel, Puebla, Mexico.
15. Basaltoide (Silvestri), monchiqose-kilauose, (II)III.5(6).2′.4. Wall of caldera, Kilauea.
b. Kersantite (Pohlmann), kilauose-akerose. Bärenstein, Thuringia, Germany.
c. Basalt (Washington), kilauose-monchiquose, III.(5)6.2.4. Monte Cuccuruddu, Keremale, Sardinia.
d. Basalt (Washington), kilauose-akerose, II(III).5′.2′.4. Mount Lisiri, Itirreddu, Sardinia.
26. Sodic gabbro=kauaiite (Cross), kilauose, III.5.2.4′. Waimea Canyon, Kauai.
e. Leucite basanite (Washington), kilauose. North of Scano, Monte Ferru, Sardinia.
f. Basalt (Pirsson), kilauose. Volcano Butte, Castle Mountains, Mont.

Analogues of Hawaiian lavas—Continued.

VIII.

	19	a	b	27	c	d	e
SiO_2	49.88	51.75	50.17	51.63	51.58	53.52	50.74
Al_2O_3	13.79	14.67	15.83	12.10	14.99	13.56	11.98
Fe_2O_3	9.65	6.27	9.32	8.67	2.04	4.93	3.41
FeO	2.61	4.73	4.87	3.10	8.36	6.61	8.11
MgO	6.12	5.19	7.21	9.40	6.51	7.37	7.25
CaO	9.59	11.94	9.34	9.17	8.59	7.39	12.42
Na_2O	3.30	2.70	3.00	3.10	3.08	3.22	2.74
K_2O	.17	.58	.71	.30	.31	.68	.24
H_2O+	.....	1.86	.74	.....	2.67	1.03	.52
H_2O-	.....	.....	.....	.....	.34	.....	.....
TiO_2	3.97	.....	.....	2.47	1.05	1.84	1.68
P_2O_5	.26	.....	.....	.26	.24	.....	0
MnO	.67	.....	.....	.30	.....	.....	.54
Sum	100.26	99.69	101.19	101.08	99.76	100.05	99.63
Quartz	5.9	6.3	2.6	4.7	2.5	6.9	1.5
Orthoclase	1.1	3.3	4.4	1.7	1.7	3.9	1.1
Albite	27.8	22.5	25.2	26.2	26.2	26.3	23.1
Anorthite	22.2	26.4	27.5	18.3	26.1	20.9	20.0
Diopside	18.1	26.2	15.0	21.0	13.6	12.7	33.5
Hypersthene	6.9	4.0	12.2	13.8	21.7	17.3	11.3
Magnetite	.....	9.0	13.5	3.0	3.0	7.2	4.9
Hematite	9.6	.....	.....	6.4	.....	.....	.....
Ilmenite	6.8	.....	.....	4.8	2.0	3.5	3.2
Apatite	.3	.....	.....	.3	.3	.....	.....
Titanite	1.0	.....	.....	.....	.....	.....	.....
	99.7	99.7	100.4	99.9	97.1	98.7	98.6

19. Basalt (Lyons), ornose, III.(4)5.3′.5. Koolau Mountains, Oahu.
a. Olivine-diabase (Cohen), auvergnose. North Kimberley, Griqualand, West South Africa.
b. Diabase porphyrite (Cohen), auvergnose. Pfandstall, Colesberg, Cape Colony, South Africa.
27. Traplike basalt (Lyons), ornose, III.(4)5.3.5. Waianae Mountains, Oahu.
c. Diabase (Melville), ornose. Mitchel Canyon, Mount Diablo, Cal.
d. Basalt obsidian (Streng), ornose. Londorf, Vogelsberg, Hesse, Germany.
e. Basalt obsidian (Cohen), ornose. Lava of 1867, Ninafou, Tonga Islands.

Analogues of Hawaiian lavas—Continued.

IX.

	A	a	b	c	d	e	f	g	h	i	j
SiO_2	50.18	50.56	52.68	50.71	47.28	48.68	48.26	48.22	51.68	50.19	48.84
Al_2O_3	14.12	14.49	14.14	14.78	13.24	15.70	14.74	14.74	13.88	14.65	14.62
Fe_2O_3	3.04	1.78	1.95	3.52	4.44	1.81	2.49	2.24	6.59	3.41	2.08
FeO	10.45	10.20	9.79	8.95	10.50	9.75	8.95	9.38	4.44	6.96	9.00
MgO	6.42	5.90	6.38	5.90	5.94	6.08	6.76	7.01	7.87	7.95	7.15
CaO	10.67	10.13	9.38	8.21	11.04	11.64	12.39	12.26	10.99	9.33	9.33
Na_2O	2.69	2.91	2.56	2.76	2.62	2.32	2.38	2.23	2.93	2.64	2.86
K_2O	.75	.38	.87	1.39	.31	.88	.90	.89	.81	.75	.89
H_2O+	.....	1.50	1.60	1.78	2.00	.10	.15	.06	.74	2.38	.49
H_2O-	.....	.20	.....	.....	.....	.....	.....	.....	.....	.66	.07
TiO_2	1.75	1.67	.....	1.92	1.48	2.68	2.81	2.72	.....	1.13	3.57
CO_2	.....	.....	.....	.25	.....	.....	.....	.....	.....	.....	.....
P_2O_5	.21	.....	.....	.....	.....	.46	.44	.38	.....	.18	.36
MnO	.19	.25	.44	.31	.40	.....	.....	.....	.....	.07	.04
BaO	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Inclusive	.....	[a].28	.....	.....	.....	.....	.....	.....	.....	.....	[b].59
Sum	100.47	100.25	99.79	100.48	99.25	100.10	100.27	100.11	99.93	100.30	99.89
Quartz	.....	.5	2.1	1.9	.....	.....	.....	.....	1.9	.8	1.4
Orthoclase	4.5	2.2	5.0	8.3	1.7	5.0	5.6	5.6	5.0	4.4	5.6
Albite	22.5	24.6	22.0	23.1	22.0	19.4	20.4	18.9	24.6	22.5	20.4
Anorthite	24.2	25.3	23.9	23.9	23.6	30.0	27.0	27.2	22.2	25.8	26.1
Diopside	22.4	20.7	18.9	13.7	25.5	20.6	26.0	25.3	25.3	15.6	13.9
Hypersthene	17.0	18.9	22.9	18.7	12.6	14.0	5.6	7.8	10.4	20.8	20.0
Olivine	1.5	.....	.....	.....	2.3	2.3	5.8	5.9	.....	.....	.....
Magnetite	4.4	2.8	3.0	5.1	6.3	2.6	2.1	3.3	9.5	4.9	3.0
Ilmenite	3.3	3.2	.....	3.5	2.8	5.2	6.8	5.2	.....	2.1	6.8
Apatite	.5	.....	.....	.....	.....	1.0	1.0	.9	.....	.3	1.0
	100.3	98.1	97.8	98.2	96.8	99.95	100.3	100.1	98.9	97.2	98.2

[a] S, 0.28.

[b] SO_3, 0.05; Cl, 0.42; NiO, 0.08; SrO, 0.04.

A. Average of nine analyses of basalt, Halemaumau, Kilauea. Camptonose-auvergnose, III.5.(3)4.4′.

a. Basalt (Diller), auvergnose. Cedar Creek, near Ophir, Oreg.

b. Dolerite (Hawes), auvergnose. Mount Holyoke, Mass.

c. Diabase (Teall), camptonose. Whin Sill, Durham, England.

d. Basalt (Teall), auvergnose. Cape Flora, Franz Josef Land.

e. Basalt bomb (Lacroix), auvergnose, III.5.4.4–5. Reunion Island.

f. Basalt (Lacroix), auvergnose, III.5.′4.4–5. Lava of 1863, Piton de la Fournaise, Reunion Island.

g. Basalt (Lacroix), auvergnose, III.5.′4.4–5. Average of eight analyses, Piton de la Fournaise, Reunion Island.

h. Olivine diabase (Cohen), camptonose. Colesburg, Cape Colony, South Africa.

i. Basalt (Lewis), auvergnose, III.5.(3)4.4′. Hartshorn's quarry, Springfield, N. J.

j. Feldspar basalt (Washington), auvergnose, III.5.4.4. Monte Ponente, island of Linosa.

Analogues of Hawaiian lavas—Continued.

x.

	29	a	b	c	d	e	30	f	g	h	i
SiO_2	50.07	52.40	52.78	48.64	51.78	51.88	49.74	47.12	44.77	47.28	47.48
Al_2O_3	13.32	13.55	13.66	14.13	12.79	14.53	12.36	14.43	12.46	13.24	12.00
Fe_2O_3	1.92	2.73	2.40	3.01	3.59	1.35	1.64	3.33	4.63	4.44	4.86
FeO	9.28	9.79	8.64	8.92	8.25	9.14	10.08	11.71	12.99	10.50	8.73
MgO	8.01	5.53	7.95	7.01	7.63	7.78	8.83	6.05	5.34	5.94	9.89
CaO	10.64	10.01	9.52	12.34	10.70	9.98	10.88	9.63	10.20	11.04	11.02
Na_2O	2.16	2.32	2.34	2.25	2.14	2.06	2.45	2.58	2.47	2.62	2.32
K_2O	.45	.40	.20	.81	.39	.93	.55	1.11	.95	.31	.48
H_2O+	.49	1.05	1.89	.08	.63	.97	.17	.34	.48	2.00	2.16
H_2O-	.22	.62	.....	.....	.....	.12	.05	.28	.12	.....	.....
TiO_2	2.70	1.08	.23	2.61	1.41	1.35	2.49	3.27	5.26	1.48	.79
CO_2	.....	.....	.....	.....	.....	.....	.....	.....	.37	.....	.....
P_2O_5	.26	.12	.....	.35	.14	.14	.41	.....	.28	.....	.....
MnO	.16	.26	.11	.....	.44	.10	.14	.....	.17	.40	.....
Inclusive	.28	.13	.....	.....	.....	.....	.33	.....	.26	.....	.....
Sum	99.97	99.99	99.72	100.15	99.89	100.33	100.08	99.85	100.75	99.25	99.73
Quartz	2.2	6.7	4.7	.....	5.4	2.1	.....	.....	.....	.....	.....
Orthoclase	2.8	2.2	1.1	5.0	2.2	5.6	3.3	6.7	5.6	1.7	2.8
Albite	18.3	19.4	19.4	18.9	17.9	17.3	21.0	22.0	21.0	22.0	19.4
Anorthite	25.0	25.6	26.4	25.9	24.5	27.6	20.9	24.5	19.5	23.6	21.1
Diopside	21.2	19.7	16.8	26.5	22.6	17.5	25.0	19.3	25.9	25.5	26.9
Hypersthene	20.9	18.1	25.7	11.2	18.7	24.4	16.9	7.3	4.0	12.6	9.3
Olivine	.....	.....	.....	3.0	.....	.....	4.6	8.6	5.9	2.3	9.5
Magnetite	2.8	3.9	3.5	4.4	5.3	2.1	2.3	4.9	6.7	6.3	7.0
Ilmenite	5.2	2.2	.5	5.0	2.7	2.6	4.7	6.3	9.9	2.8	1.5
Apatite	.6	.....	.....	1.0	.3	.3	1.0	.....	.6	.....	.....
	99.0	97.8	98.1	100.9	99.6	99.5	99.7	99.6	99.1	96.8	97.5

29. Basalt (Day), auvergnose, III.5.4.4–5. Flow of 1894 (?), Kilauea.

a. Olivine basalt (Hobbs), koghose-auvergnose, III.(4)5.4.4–5. Pine Hill, South Britain, Conn.

b. Epidiorite (Harrison), auvergnose. Urinambo, Barama River, British Guiana.

c. Basalt (Lacroix), auvergnose, III.5.4.4–5. Plaine des Osmondes, Reunion Island.

d. Dolerite (Hawes), koghose-auvergnose, III.(4)5.4.4–5. West Rock, New Haven, Conn.

e. Basaltic diabase (Lewis), auvergnose, III.5.4.4–5. Weehawken, N. J.

30. Basalt (Day and Shepherd), ornose-camptonose, III.5.3(4).4(5). Dipped from lava basin, Halemaumau, Kilauea.

f. Diabase (Washington), camptonose. Rockport, Cape Ann, Essex County, Mass.

g. Gabbro (Kemp), camptonose. Lincoln Pond, Essex County, N. Y.

h. Basalt (Teall), auvergnose. Cape Flora, Franz Josef Land.

i. Issite (Duparc and Pamphil), auvergnose, III.5.4.4–5. Kamenouchki, southern Ural Mountains, Russia.

Analogues of Hawaiian lavas—Continued.

XI.

	31	a	b	c	35	d	e	f	g
SiO_2	48.99	50.88	48.35	45.69	45.48	44.06	44.75	45.71	44.71
Al_2O_3	13.73	13.17	15.40	13.92	11.87	15.10	13.22	10.80	11.24
Fe_2O_3	1.60	1.11	4.04	3.06	1.98	5.23	1.20	4.43	5.48
FeO	10.46	9.66	4.63	9.02	9.87	7.93	10.50	9.35	8.21
MgO	13.53	13.05	11.61	11.45	13.28	9.84	10.85	13.75	14.32
CaO	7.34	10.19	10.38	10.49	10.97	12.56	11.50	10.48	10.22
Na_2O	1.62	1.17	1.87	1.76	2.21	2.20	1.95	1.58	2.50
K_2O	.27	.31	.35	.11	.77	.93	1.27	.85	1.01
H_2O+	.27	.14	3.60	.79	.74	.30	1.62	.97	.21
H_2O-	.10	.....	.....	.78	.23	.....	.....	.....	.....
TiO_2	1.73	.....	.....	2.00	1.90	1.80	3.45	1.83	2.00
CO_2	.24	.....	.08	.77	.....	.....	.....	.....	.....
P_2O_5	.13	.....	.....	.81	.25	.53	.38	.11	.37
MnO	.20	.....	.....	.....	.04	.36	.....	.17	.....
Inclusive	.17	.....	.....	.....	.19	.....	.....	.....	.....
Sum	100.38	99.67	100.31	100.65	99.94	100.84	100.71	100.13	100.27
Orthoclase	1.7	1.7	2.2	.6	4.5	5.6	7.8	5.0	6.1
Albite	13.6	10.0	15.7	14.7	12.8	11.0	10.5	13.1	13.4
Anorthite	29.2	29.7	32.5	30.0	20.6	28.6	23.4	20.0	16.4
Nephelite	.....	.....	.....	.....	2.9	4.0	3.4	.....	4.2
Diopside	5.1	16.9	15.0	13.5	26.4	24.0	24.9	26.2	24.9
Hypersthene	36.8	35.4	21.1	21.9	.....	.....	.....	6.3	.....
Olivine	7.2	4.3	4.3	6.9	24.5	15.1	20.0	18.3	22.9
Magnetite	2.3	1.6	5.8	4.4	3.0	7.4	1.9	6.5	7.9
Ilmenite	3.2	.....	.....	3.8	3.7	3.5	6.5	3.5	3.8
Apatite	.3	.....	.....	2.0	.5	1.3	1.0	.....	1.0
	99.4	99.6	96.6	97.8	98.9	100.5	99.4	98.9	100.5

31. Basalt (Cross), auvergnose, III.5.4.4–5. Flow, Olokele Canyon, Kauai.

a. Olivine-hypersthene diabase (Campbell and Brown), auvergnose. The Twins, Culpeper County, Va.

b. Greenstone (diabase) (Williams), auvergnose. Upper Quinnesec Falls, Menominee River, Wis.

c. Basalt (Schottler), auvergnose, III.5.4.4–5. Wartfeld, near Grüningen, Giessen, Hesse-Darmstadt, Germany.

35 Basalt (Cross), camptonose-auvergnose, III′.5′.(3)4.4–5. Flow, Olokele Canyon, Kauai.

d. Basalt (v. John), auvergnose. Punta Delgada, San Miguel, Azores.

e. Olivine basalt (Lacroix), camptonose-auvergnose, III.5′.(3)4.4–5. Papenoo Valley, Tahiti.

f. Hornblende picrite (Iddings), auvergnose, III′.5.4′.5. Conical Peak, Crazy Mountains, Mont.

g. Basalt (Reinisch), limburgose-camptonose, III(IV).5(6).3.4. Heard Island, Antarctic region.

Analogues of Hawaiian lavas—Continued.

XII.

	36	a	b	37	40	c	d	e	f
SiO_2	36.85	43.76	44.78	35.86	36.34	36.53	37.98	39.47	37.96
Al_2O_3	11.97	11.58	12.76	12.10	10.14	9.91	9.30	11.26	10.14
Fe_2O_3	13.90	4.39	5.42	7.82	6.53	3.84	5.96	8.74	3.69
FeO	6.54	7.57	8.34	8.09	10.66	6.01	5.86	4.98	7.59
MgO	10.73	12.97	10.17	9.72	10.68	18.10	17.13	14.33	14.69
CaO	9.00	9.64	10.23	12.08	13.10	10.31	10.38	12.08	16.28
Na_2O	4.13	3.03	3.56	6.23	4.54	3.06	3.50	5.04	2.18
K_2O	.79	1.84	1.81	1.93	1.78	1.60	2.03	1.86	.69
H_2O+	.....	.47	1.42	.....	1.00	.....	2.74	.63	1.82
H_2O-	.....	.....	.....	.....	1.00	.....	.....	.....	.39
TiO_2	4.05	3.41	.25	2.90	2.87	8.38	2.02	1.56	2.93
CO_2	.....	.38	.93	.....	.15	.....	.36	.....	.....
P_2O_5	1.25	.45	.92	1.08	1.02	.....	.31	.99	1.13
MnO	1.13	.....	.....	.39	.20	.....	.....	.....	.22
BaO	.....	.....	.....	.....	.....	.....	.....	.....	.06
Inclusive	.28	.29	.....	1.92	.04	2.90	2.49	.....	.33
Sum	100.62	99.78	100.59	100.12	100.05	100.64	100.15	100.94	100.13
Orthoclase	4.5	11.1	11.1	.....	.....	.....	.....	.....	.....
Albite	10.0	10.5	10.0	.....	.....	.....	.....	.....	.....
Anorthite	12.2	12.5	13.3	.....	1.7	8.6	3.9	2.8	18.6
Nephelite	13.4	8.2	10.8	28.1	21.0	13.9	15.9	22.7	9.9
Leucite	.....	.....	.....	8.7	8.3	7.4	9.2	8.7	3.1
Acmite	.....	.....	.....	.5	.....	.....	.....	.....	.....
Diopside	19.4	23.7	25.6	13.4	17.4	22.0	21.6	22.7	13.5
Olivine	12.5	18.3	17.3	16.3	20.2	24.6	25.6	17.7	26.1
Akermanite	.....	.....	.....	12.2	12.0	[a] 5.6	4.9	8.1	13.8
Magnetite	13.0	6.5	7.9	11.1	9.5	.....	8.6	12.5	5.3
Hematite	5.0	6.0	.....	.....	.....	3.8	.....	.....	.....
Ilmenite	7.7	6.5	.5	5.5	5.5	9.9	3.9	3.1	4.4
Apatite	2.7	1.0	2.0	2.7	2.4	.....	.7	2.2	2.6
Chromite	.....	.....	.....	.....	.....	4.3	.....	.....	.....
	100.4	98.3	98.5	98.5	98.0	100.1	94.3	100.5	97.3

[a] Perofskite.

36. Basaltic scoria (Lyons), monchiquose-(unnamed), III(IV).6′.2(3).(4)5. Cinder cone, Punahou, near Honolulu, Oahu.

a. Nephelite basalt (Klautsch), monchiquose-limburgose, III′.6.(2)3.4. Lava of 1905–6, Matavuna volcano, Savaii, Samoan Islands.

b. Basalt (Beyschlag), limburgose. Hünenberg, Blatt Melsungen, Prussia.

37. Black sand (Lyons), (unnamed)-casselose, (III)IV.2.$_{4}$.2(.3).2′. Recent lapilli, Punahou, near Honolulu, Oahu.

40. Nephelite-melilite basalt (Cross), uvaldose-casselose, ′IV.2.$_{(3)4}$.2(3).2(3). Moiliili, near Honolulu, Oahu.

c. Melilite basalt (Grubenmann), uvaldose. Wartenberg, Hegau, Baden.

d. Melilite-nephelite basalt (Rinne), uvaldose. Hohenberg, Bühne, Westphalia.

e. Nephelite basalt (Stock), uvaldose. Schafberg Plateau, Lobauerberg, Saxony.

f. Nephelite-melilite basalt (Cross), casselose. Near Uvalde, Uvalde County, Tex.

Analogues of Hawaiian lavas—Continued.

XIII.

	38	a	b	39	c	d	e
SiO_2	48.57	45.71	49.02	42.99	48.29	41.03	41.50
Al_2O_3	10.51	10.80	10.14	10.21	10.00	11.07	12.31
Fe_2O_3	2.19	4.43	1.54	3.01	2.93	4.65	5.20
FeO	9.45	9.35	10.46	10.28	5.46	7.05	8.46
MgO	17.53	13.75	17.25	14.61	17.22	15.75	11.29
CaO	8.06	10.48	8.29	12.54	11.80	10.59	14.05
Na_2O	1.59	1.58	1.59	1.40	2.78	1.71	2.06
K_2O	.34	.85	.40	.52	.45	.94	.48
H_2O+	.37	.97	.75	1.10	1.95	1.36	.50
H_2O-	.10	.....	.....	.82	.....	2.85	.....
TiO_2	1.48	1.83	.99	2.52	.....	2.43	4.78
P_2O_5	.19	.11	.11	.29	.....	.41	.06
MnO	.16	.17	.16	.17	.....	.....	.....
Inclusive	.18	.....	.....	.12	.....	.....	.....
Sum	100.72	100.13	100.70	100.58	100.88	99.84	100.69
Orthoclase	2.2	5.0	2.2	2.8	2.8	5.6	2.8
Albite	13.6	13.1	13.6	6.3	13.1	6.3	3.1
Anorthite	20.3	20.0	19.2	20.0	13.3	20.0	23.1
Nephelite	.....	.....	.....	3.1	5.7	4.3	7.7
Diopside	14.9	26.2	17.0	32.3	35.7	23.6	36.7
Hypersthene	23.9	6.3	22.9	.....	.....	.....	.....
Olivine	18.7	18.3	20.7	24.2	24.1	23.7	10.1
Magnetite	3.3	6.5	2.1	4.4	4.2	6.7	7.7
Ilmenite	2.9	3.5	2.0	4.7	.....	4.6	9.1
Apatite	.4	.....	.3	.7	.....	1.0	.....
	100.2	98.9	100.0	98.5	98.9	95.8	100.3

38. Ultrafemic olivine basalt (Daly), palisadose-hilose, (III)IV.1(2).2.1(2).2. Flow of 1852, Mauna Loa, Hawaii.

a. Hornblende picrite (Iddings), auvergnose, Conical Peak, Crazy Mountains, Mont.

b. Olivine diabase (Lewis), palisadose, Englewood Cliffs, N. J.

39. Picritic basalt (Cross), rosseinose-uvaldose, 'IV(1)2.'32.2. Summit of Mount Haleakala, Maui.

c. Gabbro (Sachse and Becker), rosseinose. Etzdorf, Rosswein, Saxony.

d. Trachydolerite (Bücking), auvergnose, III(IV).5(6).4.4–5. Platzer Kuppe, Rhöngebirge, Germany.

e. Essexitic gabbro (Lacroix), unnamed subrang, (III)IV.2.2.2.2. Papenoo Valley, Tahiti.

Analogues of Hawaiian lavas—Continued.

XIV.

	41	a	b	c	42	d	43	e	f	g
SiO_2	47.25	47.75	39.07	40.79	46.59	48.15	37.50	39.92	38.87	39.16
Al_2O_3	9.07	10.56	9.95	10.41	7.69	9.52	9.12	8.60	11.94	10.06
Fe_2O_3	1.45	.74	5.15	3.52	2.20	2.98	5.59	4.40	4.02	6.54
FeO	10.41	8.34	10.37	6.39	10.46	5.46	8.81	8.00	6.00	7.71
MgO	19.96	19.09	19.19	23.34	21.79	17.42	13.72	20.17	15.24	13.74
CaO	7.88	9.62	6.29	8.48	7.41	11.91	13.85	10.68	10.87	15.30
Na_2O	1.38	1.32	.97	1.71	1.33	2.34	2.69	1.91	2.59	2.38
K_2O	.35	.12	.19	.71	.28	.40	.63	1.03	1.64	1.46
H_2O+	.04	2.06	7.65	4.04	.37	2.35	2.35	1.45	.....	1.55
H_2O-	.08	.05	.....	.....	.04	.....	1.05	.43	.....	.....
TiO_2	1.61	.37	.68	.....	1.83	.....	3.21	2.70	4.79	1.52
CO_2	.....	.....	.09	.....	.....	.....	.27	.....	.....	.58
P_2O_5	.21	.03	.13	.....	.11	.....	.90	.51	.....	.75
MnO	.13	.10	.17	.....	.18	.....	.15	.24	.....	.11
BaO	.....	.....	.....	.....	.....	.....	.07	.06	.....	.....
Inclusive	.21	.31	.05	.....	.25	.....	.28	.35	3.06	.....
Sum	100.03	100.46	99.95	99.39	100.53	100.53	100.19	100.45	99.02	100.86
Orthoclase	1.7	.6	1.1	2.8	1.7	2.2	.....	.....	.....	.....
Albite	11.5	11.0	8.4	.....	11.0	14.7	.....	.....	.....	.....
Anorthite	17.8	22.8	22.2	18.9	14.7	14.2	11.1	12.0	16.1	12.2
Nephelite	.....	.....	.....	7.7	.....	2.8	12.2	8.5	11.9	11.1
Leucite	.....	.....	.....	.9	.....	.....	2.6	4.9	7.4	7.0
Diopside	16.2	19.8	6.6	18.4	16.8	35.4	31.0	24.6	25.0	16.7
Hypersthene	19.5	16.3	9.7	.....	17.9	.....	.....	.....	.....	.....
Olivine	27.4	25.8	34.3	41.6	30.8	24.5	18.6	32.1	18.5	23.3
Akermanite	.....	.....	.....	.....	.....	.....	3.9	2.4	2.0	13.7
Magnetite	2.1	.9	7.7	5.1	3.3	4.4	8.1	6.3	1.2	9.5
Hematite	.....	.....	.....	.....	.....	.....	.....	.....	3.2	.....
Ilmenite	3.0	.8	1.4	.....	3.5	.....	6.1	5.1	8.9	2.8
Apatite	.3	.....	.3	.....	.3	.....	2.0	1.2	.....	1.8
Chromite	.....	.....	.....	.....	.2	.....	.....	.....	4.5	.....
	99.5	98.0	91.7	95.4	100.2	98.2	95.6	97.1	98.7	98.1

41. Picritic basalt (Cross), Rossweinose-wehrlose, 'IV.1'.3.1(2).2. Flow of 1840, Nanawale, Puna, Hawaii.

a. Diabase? (Turner), rossweinose. Cathay Hill, Mariposa County, Cal.

b. Picrite. Sechshelden, Nassau.

c. Picrite-porphyrite (Tschermak), custerose. Gümbelberg, Neutitschein, Moravia.

42. Porphyritic gabbro (Daly), rossweinose-wehrlose, IV.1(2).3.1(2).2. Uwekahuna laccolith, Kilauea, Hawaii.

d. Gabbro (Sachsse and Becker), rossweinose. Etzdorf, Rosswein, Saxony.

43. Nephelite-melilite basalt (Cross), uvaldose, IV.2.3.2.2. Kilauea Landing, north coast of Kauai.

e. Nephelite basalt (Cross). Black Mountain, Uvalde County, Tex.

f. Melilite basalt (Grubenmann). Hohenhöwen, Hegau, Baden.

g. Nephelite basalt (Leppla and Schwager). Oberleinleiter, Franken Jura, Bavaria.

General facts of distribution.—The foregoing table presents clearly many features which it is almost superfluous to repeat in words. But it may be well to summarize some of the more important facts. The analogues of Hawaiian magmas are widely distributed over the world, 36 occurring in various countries of Europe, 32 in North America, 10 in Africa or the adjacent island of Reunion, 11 in other islands of the Pacific, and a few others in scattered localities. Continental Asia has no representative and South America only one, but this is surely due to the degree of similarity sought for and to meager material for comparison. The broad facts are shown in the table given below. The roman numerals at the head of the columns refer to the corresponding divisions of the preceding table.

Distribution of analogous rocks.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
Oceanica:														
Tahiti	1					2					1		1	
Samoa												1		
Tonga								1						
New Zealand						1								
Auckland				1										
Australia						1								
Japan						1								
North America:														
California and Oregon			1		2			1	1					1
Mexico					1		1							
Montana	2						1				1		1	
Colorado and Utah		2	1											
Yellowstone National Park	1			3										
Texas												1		1
Minnesota and Wisconsin					1						1			
New Jersey-Virginia									1	1	1		1	
New England	2			1		1			1	3				
Europe:														
England and Scotland			1		1	1			1					
Germany	1			2	2	1	1	1			1	4	2	4
Norway	2	2	1											
Finland		1												
Sardinia			1		1		3							
Africa:														
Transvaal		1												
Cape Colony								1	1					
Reunion		1	1	1					2	1				
South America										1				

Analogous rocks of Oceanica.—It would seem natural to find that other island groups of the Pacific contained lavas very similar to those of Hawaii. But such similarity is not very clearly shown by the meager chemical data at hand for some of the groups most nearly resembling Hawaii in general character. It is highly probable, however, that future work will disclose strong analogies between Hawaii and several of the groups of Oceanica.

The rocks of Tahiti, recently described by Lacroix,[1] with analyses by Pisani and Boiteau, bear the closest analogy to those of Hawaii. The Tahiti analogues come mostly from the deep-cut valley of Papenoo and embrace both lavas and granular intrusives. Of two Papenoo basalts, one is an analogue of an olivine-rich basalt of Olokele Canyon, Kauai (No. 35), and the other of a basalt from the caldera walls of Kilauea (No. 11). Of the granular intrusives of Tahiti, a rock called "gabbro néphélinique" or theralith by Lacroix is like another basalt of the wall of Kilauea (No. 9), and a "gabbro essexitique" corresponds to the summit picritic basalt of Haleakala (No. 39). Although the "gabbro essexitique" has no lenad, according to Lacroix, the norm contains 7.7 per cent of nephelite, which is more than twice that in the picritic basalt of Haleakala.

[1] Soc. géol. France Bull., 4th ser., vol. 10, pp. 91–124, 1910.

There is also a lava of Tahiti, called phonolite by Lacroix, although it contains but little nephelite, which is very near the trachytic obsidian of Puu Waawaa in composition, as the French petrographer has pointed out.[1] Lacroix also describes tinguaite (miaskose), syenite (borolanose), nephelite syenite, nephelite monzonite, camptonite, and hauynophyre (all these four belonging to essexose), microgabbro (camptonose), and picrite (custerose), in addition to those forms which are more particularly compared with rocks of Hawaii. The prevalent resemblance to rocks commonly referred to the alkalic series is recognized by Lacroix.

The significance of this similarity between the rocks of Tahiti and Hawaii is emphasized by the fact that the more direct analogues include highly salic, intermediate, and strongly femic magmas, suggesting similar lines of differentiation at the two centers.

The lavas of the Samoan Islands, formerly referred to in general terms as basaltic, may very likely be found to possess as great a variety as is exhibited by those of Hawaii. How great a similarity exists between these lava series remains to be determined, but Weber[2] has shown the existence in the several islands of the Samoan group of common plagioclase-olivine basalt, limburgite, several nephelite-bearing varieties included under trachydolerite, phonolite, and alkali trachyte. Unfortunately the analyses given by Weber (Dr. Hobein, analyst) are too incomplete and otherwise inadequate to furnish a basis for satisfactory chemical study. It seems plain that in a general way the Samoan and Hawaiian rock series show many interesting points of similarity.

The single rock of Samoa shown by analysis to be a close analogue of a Hawaiian type is the lava of 1905–6 from the great volcano of Matavuna, on Savaii, described by Klautsch.[3] As shown in the table, this lava approximates in composition a scoria from a small recent cinder cone at Punahou, near Honolulu, and is quite different from the lavas of the large Hawaiian volcanoes. In contrast to this relation of the Matavuna lava, it appears that the lava of 1867 in the Tonga group is very near one of the old basalts of Oahu.

Comparison with rocks of Reunion.—The most striking analogy noted is between the lavas of Hawaii and those of the island of Reunion, recently described by Lacroix,[4] who recognizes the similarity. It appears that the lavas of the active center of the Piton de la Fournaise bear a close resemblance both in range of variation and in average composition to those of Kilauea. Lacroix presents analyses of these recent lavas, most of them belonging to auvergnose, and has calculated their average. This average and the analyses of two individual rocks are compared in Division IX of the table (p. 72) with the average of nine analyses from Halemaumau. This mean of the Reunion rocks is still nearer, however, to the two lavas of Halemaumau given in Division X.

Aside from this analogy of recent lavas it is of particular interest to find that among the older lavas on the flanks of the extinct and dissected Piton de Neiges, Reunion, are several close analogues of Hawaiian types not found at Kilauea. One of these corresponds to the kohalaite (Division II), another to the trachydolerite of Daly from Mauna Kea (Division III), and a third to the trachydolerite from Haleakala (Division IV). A feldspathic picrite lava alternates with trachydolerite in some places, further emphasizing the relation to conditions in Haleakala.

European analogues.—Among the countries of Europe, Germany has the greatest number of rocks resembling those of Hawaii in composition. These rocks come from widely separated localities, but a considerable number of them occur in Hesse, Nassau, and the Rhoen Mountains. The German rocks cited are analogues of several of the more salic lavas and especially of the ultrabasic lavas of Divisions XII, XIII, and XIV of the table. Rather singularly, the modern lavas of Kilauea and the normal basalts of Kauai have no discovered close analogues among German rocks, though such analogues doubtless exist.

The extremely salic lavas of Divisions I, II, and III find counterparts in Norway among the alkalic rocks of the Christiania region, but here the detected analogy ends. The intermediate and basic rocks of Hawaii seem to have no equivalents in Norway. Comment will be made on this point later on.

[1] Op. cit., p. 124.
[2] K. bayer. Akad. Wiss. math.-phys. Klasse Abh., vol. 24, pt. 2, pp. 287-310, 1909.
[3] K. preuss. geol. Landesanstalt Jahrb., 1907, p. 174.
[4] Compt. Rend., vol. 155, pp. 538-54, 1913.

A notable number of Hawaiian types, including older lavas of Kilauea and three of the more alkalic rocks, find analogues in Sardinia.

No other district is particularly noteworthy on account of the number of its rocks standing in close relationship to those of Hawaii, but there are points of interest attaching to many of the analogies brought out in the table which will be emphasized in the theoretical discussion.

THEORETICAL BEARINGS OF DATA PRESENTED.

GEOGRAPHIC DISTINCTION BETWEEN ATLANTIC AND PACIFIC REGIONS.

It is perhaps unnecessary to register any further protest against the use of the terms Atlantic and Pacific as expressing the distribution of the so-called Alkalic and Calcic branches or Sippen of igneous rocks. But a brief résumé of the situation seems appropriate in this place.

The original proposition by Harker [1] was to distinguish "an Atlantic and a Pacific facies of igneous rocks, corresponding with distinct phases in crust movements of a large order." But he later made the more definite generalization that these "branches" were geographically restricted in their distribution in the "Atlantic and Pacific regions," which he outlined.[2]

The work of Weber, Lacroix, Daly, and myself, together with scattered evidence from many quarters, demonstrates that the Pacific island groups are characterized by alkalic rather than by calcic magmas. On the shores of the Pacific are many occurrences of alkalic rocks. It is therefore not appropriate to use the terms Atlantic and Pacific for petrographic regions supposed to be characterized by chemically different magmas.

The primary idea of Harker and Becke was to make a petrogenetic generalization parallel to that of Suess as to the tectonic differences of the mountain ranges adjacent to the two oceanic basins. Whatever relation may exist between tectonic and petrographic provinces, its nature has not yet been established, and Harker [3] has abandoned, tentatively at least, the use of the terms Atlantic and Pacific for the Alkalic and Calcic branches of igneous rocks.

REFERENCE OF HAWAIIAN LAVAS TO ALKALIC OR CALCIC SERIES.

With the data of chemical and mineral composition and association of Hawaiian volcanic rocks and the world-wide occurrence of analogous types before us, it remains to see whether these facts substantiate or refute the genetic and systematic generalizations as to the distinction between the Alkalic and Calcic series. The Hawaiian lavas have been generally considered by petrographers as true basalts—an assignment which refers them to the Calcic series. Rosenbusch [4] cites one analysis of a lava of Kilauea (No. 23 of the table on p. 48) and one of Mauna Loa (No. 32) as of true basalts. Harker [5] considers that the trachyte of Puu Waawaa is not sufficient to throw discredit on the designation of the Hawaiian rocks and those of other Pacific island groups as assemblages of typical subalkalic (calcic) character.

Soda trachytes.—Of the two soda trachytes of Division I of the table of analogues, the rock of Puu Waawaa (No. 2) must surely be considered a true alkali trachyte, in the Rosenbusch sense, as it contains no normative anorthite. But the rock of Lahaina (No. 1) has 3.61 per cent of normative anorthite, and as some of the soda is present in ægirite the mode of this rock must contain correspondingly more anorthite in its plagioclase. Were the same rule applied to the syenites as to the granites this trachyte would belong to the Calcic series. But it contains ægirite, and the names and associations of the analogous rocks show them to be currently considered as typically alkalic.

Kohalaite.—The kohalaite of Division II of the table has normative oligoclase ($\pm Ab_4An_1$). Unfortunately, I do not know the mode of this rock, analyzed by Lyons and said to be a dense gray lava, and I have found no close analogue among surface rocks. As the table shows, its

[1] Science Progress, vol. 6, p. 26, 1896.
[2] Natural history of igneous rocks, pp. 93–100, London, 1909.
[3] British Assoc. Adv. Sci., Section C, Presidential Address, p. 4, Portsmouth, 1911.
[4] Elemente der Gesteinslehre, 3d ed., p. 399, Stuttgart, 1910.
[5] Op. cit., pp. 96–97.

nearest relatives are leeuwfonteinite, nation minette, akerite, and augite syenite of well-known regions of markedly alkalic types. But the two monzonite porphyries, d and f of Division II, raise interesting questions for consideration.

The rock marked f is the most highly alkalic type of the original Gilbert collection from the Henry Mountains,[1] associated with intrusive types of quartz monzonite and quartz diorite porphyries such as are common in the Rocky Mountain region and surely can not be regarded as of the Alkalic series. Its augite is strongly colored by the ægirite molecule but retains a large extinction angle. The rock is richer in alkalies than the kohalaite or any of the cited analogues and is poorer in lime than most of them. It is considerably poorer in lime and normative anorthite than the akerite of Ramnas, cited also by Rosenbusch[2] as typical of its group of the alkali syenites.

The other monzonite porphyry (d) compared with kohalaite, while not so near it as the rock of the Henry Mountains, is certainly of very similar character. Its associates in the La Plata Mountains, Colo., are monzonite, augite syenite, various quartz monzonite porphyries, lamprophyres allied to camptonite, etc. Some of these might be called alkalic in the Rosenbusch sense, but others do not seem to be so.

Kohalaite has, then, some rather marked chemical features requiring its assignment to an Alkalic series. Its analogues are mainly associates of pronounced alkalic types, partly of calcic assemblages.

Trachyandesites.—The rocks of Haleakala (Division III of the table) are evidently of trachyandesitic character, and their analogues are recognized as of the Alkalic series. Rosenbusch[3] cites, under trachydolerite, the same analysis of mugearite given in the table and also one of basalt from San Mateo, Sardinia, probably the same rock of which I quote a new analysis by Washington. Lacroix[4] compares the trachyandesite of Reunion with mugearite. The rock of Bull Cliff, Cripple Creek, Colo., is associated with phonolites in a marked alkalic center. Carmeloite is called an augite andesite by Rosenbusch,[5] but its normative composition seems to place it systematically very near to the trachyandesite of Haleakala. As the norms show, one phase of the rhombic porphyry of Norway belongs in this group.

Rocks of Mauna Kea.—The lavas of Mauna Kea described by Daly (Division IV of the table) contain much more normative anorthite than the trachyandesites, and although Daly calls one of them trachydolerite, I am not sure where they would have been placed by Rosenbusch on the basis of composition. The analogous rocks of the table are apparently calcic and occur in districts where alkalic rocks also occur. Pirsson[6] has pointed out this relation of the norite with umptekite, monzonite, camptonite, and gabbro. The basalt of Reunion has both alkalic and calcic associates according to Lacroix.[7] The andesites of the Yellowstone have not been questioned by Rosenbusch but have various alkalic associates in the park. The rocks of the Harz Mountains seem calcic. Altogether I should say that the Mauna Kea rocks are intermediate but have striking analogues of more clearly calcic affinities.

Rocks of Division V.—The two similar feldspathic basalts of Division V of the table, analyzed but not microscopically described by Lyons, are poor in normative quartz and orthoclase, with anorthite nearly equal to albite. The normative plagioclase would be andesine near labradorite. From the composition they appear to be calcic, and most of the analogues of the table occur in districts where alkalic rocks do not prevail. The olivine dolerite of Skye is included in the table, in spite of its normative olivine, to show the nearest Hawaiian analogue of the rock which, according to Harker, is a part of the same mass as the mugearite of Division III.

These basalts are intermediate and from my standpoint might be expected to have analogues of various associations in different districts.

Rocks of Kilauea's caldera walls.—Division VI of the table deals with three of Silvestri's rocks from the caldera walls of Kilauea, one of which he calls augite andesite. The first two

[1] U. S. Geol. Survey Fourteenth Ann. Rept., pp. 176, 226, 1894.
[2] Elemente der Gesteinslehre, 3d ed., p. 132, Stuttgart, 1910.
[3] Op. cit., p. 440.
[4] Compt. Rend., vol. 155, p. 540 (analysis 3).
[5] Op. cit., p. 380.
[6] Am. Jour. Sci., 4th ser., vol. 31, p. 428, 1911.
[7] Op. cit., p. 544.

(Nos. 9 and 11) appear to have the chemical character of trachydolerites, for they carry normative nephelite and olivine and are richer in orthoclase than the common basalt of Hawaii. The analogues of these rocks are also rather alkalic types—two of them from Tahiti.

The basalt No. 12, while free from normative nephelite, has a higher proportion of alkali feldspars than the other types of Division VI. The analogous rocks of Japan, New South Wales, and Scotland are recognized by Kozu, Card, and Tyrrell, respectively, as containing more alkali feldspar than normal basalt, and it may be assumed that they belong in the trachydolerite group of Rosenbusch.

The allied rocks of Division VII are so distinctly alkalic through the subordination of normative anorthite that their reference to the Alkalic series can not be questioned. It is interesting to note that one of the analogous types occurs in Cerro San Miguel, Mexico. Three of the analogues of this division are from Sardinia.

Basalts of Oahu.—The Oahu basalts of Division VIII are unusual types, and as they have not been described in detail by Lyons the accuracy of the analyses might be questioned were it not a fact that many Oahu basalts are poor in olivine and rich in bronzite (p. 19). The Oahu basalts have very low potash, and, although alkali feldspars exceed the anorthite in the norms, I should suppose that such magmas must be assigned to the Calcic series. The only close analogues found are not helpful in deciding this question. They are all more calcic and the analyses are more or less questionable, except that by Melville of a somewhat altered rock from Mount Diablo, Cal.

Average lava of Halemaumau.—The relations of the modern lavas of Halemaumau to the so-called Alkalic and Calcic series are of almost critical importance in the discussion of the merits of the theoretical conceptions or systematic uses made of those series. In Division IX of the table is given the average composition of nine lavas of Halemaumau and in Division X the two most recent analyses. The data of these divisions may well be discussed together.

The analyses and norms give no ground, so far as I can see, for changing the reference of these rocks to the normal basalts, in accordance with the views of all petrographers who have discussed them, unless the normative quartz or low olivine is held to require an assignment to augite andesite. The normative plagioclase of the average is labradorite near andesine.

Let us now apply the three rules given by Rosenbusch as of value in deciding between the alkalic and calcic relations in such cases. First, there is no nephelite or other lenad, normative or modal, and no sodic pyroxene or amphibole. Second, the sum of the alkalies is only about 3 per cent, while 5 per cent is the limit cautiously set by Rosenbusch above which one may suspect trachydoleritic affinities. Third, the character and associations of analogous rocks clearly support the reference to the Calcic series.

Among the closely analogous rocks cited in the table are five Triassic diabases of the eastern United States defined by Rosenbusch as typical of the Calcic series. Besides the cited rocks many others might have been noted, showing a very notable, general, or specific resemblance to several lavas of Hawaii. Rosenbusch [1] quotes the cited analysis of diabase from West Rock, Conn., as representative of "Hunnediabas."

The Whin Sill of England is also "Hunnediabas," according to Rosenbusch,[1] who cites an analysis of that rock from Durham corresponding closely to that of a rock from the same locality quoted in Division IX of the table. The Whin Sill is less strongly calcic than the Kilauea lavas with which it is compared.

In Cape Colony, South Africa, Rosenbusch [1] finds another representative of "Hunnediabas" which is similar to the rock of Colesburg, South Africa, cited in Division IX. The resemblance between the recent lavas of Piton de la Fournaise, on Reunion Island, and those of Halemaumau has been noted (p. 81) and is illustrated in Divisions IX and X. The island of Linosa furnishes another significant analogue.

Basalts of Kauai.—Two adjacent basalt flows of Olokele Canyon, Kauai, cited in Division XI, appear, from analysis and mode, to be highly calcic, though they vary in silica so that one

[1] Op. cit., p. 410.

has normative nephelite while the other has not. One of these rocks (No. 31) is the chrysophyre containing modal tridymite and cristobalite. (See p. 11.) The only closely analogous basalt I have found is one from Hesse-Darmstadt. A near analogue is an olivine-hypersthene diabase of Culpeper County, Va., cited by Rosenbusch [1] as a calcic diabase. Another is an old greenstone diabase of the Lake Superior region.

The second basalt of Division XI has fairly close analogues in basalts of the Azores and Tahiti and a picrite of the Crazy Mountains, Mont. These may be considered by some petrographers as alkalic because of their associated rocks, but the value of such a conclusion is brought in question by the direct association, in Olokele Canyon, of the two rocks of Division XI.

Femic basalts near Honolulu.—The three Oahu rocks of Division XII are of local and comparatively recent eruptions near Honolulu, regarded as extreme products of subsidiary differentiation. (See p. 91.) They undoubtedly show characters requiring their reference, under current ideas, to the Alkalic series, and this conclusion is confirmed by the analogues and their associates. All these lavas belong in the class of lamprophyric effusives recently given definite recognition by Rosenbusch,[2] who quotes the lava of 1905–6 from Matavuna (a, Division XII) as one of the Alkalic series.[3]

The interesting and significant point here is that of genetic relation to the prevalent hypersthene-bearing, olivine-poor basalts of Oahu, such as are represented in Division VIII, which seem to indicate approximately the probable calcic nature of the original magma of Oahu.

Picritic basalts of Mauna Loa and Haleakala.—Two of the most basic lavas of the large centers are cited in Division XIII. The Mauna Loa flow of 1852 is decidedly calcic as to its normative molecules and has no nephelite. The lava of Haleakala, with considerably more lime and even less soda than the Mauna Loa rock, has normative nephelite, which is so clearly a result of the lower silica that it seems unreasonable to give the nephelite any weight as showing alkalic character.

As to the home associations of these types, the lavas of Mauna Loa are not yet known to include alkalic varieties, and Rosenbusch cites one of these lavas as a true (calcic) basalt. The basalt of Haleakala, however, is closely associated with trachyandesite of undoubted alkalic stamp.

The cited analogues are mostly intrusive rocks or lavas of centers where alkalic types abound, but in Tahiti, at least, other more calcic forms are known. The olivine diabase of Englewood Cliffs, N. J., so very near to the Mauna Loa lava, is one of the Triassic traps of the Eastern States, other members of which resemble lavas of Kilauea, as has been shown above. The analogy with the gabbro of Rosswein is not very close, this rock being relatively alkalic in its salic elements.

Division XIV.—The three most femic rocks of Hawaii thus far analyzed are dealt with in Division XIV of the table. Two of these are nearly related chemically—one from Kilauea (No. 42), the other erupted in Puna (No. 41) but perhaps a direct product of the Kilauea reservoir. No. 41 is a picrite basalt and No. 42 is called by Daly porphyritic gabbro, but both rocks are so rich in magnesia and so poor in alumina as to fall with the picrites, these being defined as effusive forms of peridotites, in agreement with Rosenbusch. No Tertiary lavas have been found for comparison with these fresh Hawaiian flows, and the nearest analogues are the picrites and gabbros of Division XIV.

The analogues of the nephelite-melilite basalt (No. 43) are all rocks which must be called alkalic by adherents of the Rosenbusch system.

Résumé.—On applying Rosenbusch's rules to the analyzed lavas of Hawaii, it appears that about 15 of them are referable to the Alkalic series, that a somewhat larger number are as clearly of the Calcic series, and that a smaller number are of questionable affinities. The dominant basalts of the islands, as shown by both chemical and microscopical data, are true basalts,

[1] Op. cit., p. 410. [2] Idem. p. 473. [3] Idem, p. 483.

or "gabbroic effusives," to use the expression of Rosenbusch,[1] but essexitic effusives, or trachydolerites, also occur. The alkalic types are known on all the main islands except Molokai, no rocks from that center having been analyzed.

THE ALKALIC AND CALCIC SERIES OF IGNEOUS ROCKS.

Current views regarding the series.—The sharp and far-reaching distinction between the Alkalic (granito-dioritic) and Calcic (foyaitic-theralitic, alkalicalc) series among igneous rocks is often referred to in petrographic literature as the most important contribution to petrography made by Rosenbusch. The fundamental significance of the distinction is tacitly admitted in most discussions of petrogenesis, and the application of this principle in systematic classification as attempted by Rosenbusch has seldom been criticized. Still it must be admitted by all petrographers that the criteria for separating rocks of the two series have not been clearly formulated and that the generalizations as to occurrence and association deserve the closest scrutiny on the basis of observation. The study of the Hawaiian rocks, generally treated as belonging to the Calcic series but including many analogues of alkalic types, furnishes a basis for testing the truth of oft-repeated assertions concerning the natural relations of the two great series.

One may search petrographic literature in vain for a clear statement as to the distinctive characters of the series or the criteria for recognizing them or an explanation why closely similar rocks of intermediate composition must nevertheless be divided between two series of almost antagonistic relations to each other. When the thoughtful student of the complex relations of igneous rocks reviews the strongly stated generalizations as to the contrasting characters and independent occurrence of the Alkalic and Calcic series, and the basis of fact on which they rest, he must conclude that those generalizations have been hastily drawn and go much too far. There is reason to recall many instances where incorrect and extravagant generalizations have retarded the development of petrographic system.

In the Elemente der Gesteinslehre Rosenbusch carries through, so far as he is able, the distinction between alkalic and calcic rocks, and as his classification in that work is based on chemical data and is illustrated by tables of chemical analyses, one might naturally expect to find some justification for the idea of the two rock series; but in fact, although the question is of such fundamental importance, it is not discussed at all except incidentally.

The first mention of the two series comes not where the system is outlined but under the description of granite. After the simple statement [2] that alkali granite contains no lime-soda feldspar, in distinction to alkalicalc granites, follows [3] the bare, unqualified assertion that the two granite groups occur in different geologic provinces and with different accompanying dike rocks. It is further asserted that alkali granites are associated only with alkali syenites, nephelite syenites, essexites, and their basic relatives, and similar restrictions are placed on the associations of alkalicalc granites. The syenites are avowedly but not actually treated like the granites.

Some of the alkalicalc granites and corresponding syenites cited by Rosenbusch contain less than 1 per cent of lime entering into anorthite, as calculated by him (on the principle of the norm) from the excess of alumina, after soda and potash have been satisfied. One is tempted to inquire how it can be supposed that differentiation may be assumed to have proceeded so far, within the alkalicalc series, without allowing the possibility of the next small step by which the alkalies might increase, relatively, to the point where the molecular ratio of alkalies to alumina becomes 1:1.

It is noted by Rosenbusch [4] that the alkalicalc granites are very much more abundant than the corresponding syenites. That peculiar situation is, in my opinion, due mainly to the fact that lime feldspar bearing associates of alkali granites are, on an arbitrary principle, not recognized by Rosenbusch as possible, while larvikite, akerite, and other rocks carrying considerable normative anorthite are treated as alkali syenites (!) and as grading into the monzonites, a truly intermediate group, which Rosenbusch is forced to treat as belonging with

[1] Op. cit., p. 402. [2] Idem, p. 78. [3] Idem, p. 84. [4] Idem, p. 119.

the Alkalic series. He recognizes the fact that an alkali granite can not grade through quartz monzonite and granodiorite into quartz diorite, or the distinction of Alkalic and Calcic series fails, even among the most highly salic rocks.

The distinction of essexites and trachydolerites, through their inherent characters as alkali rocks, from gabbro and basalt is admitted by Rosenbusch [1] to be at the present time impossible because the characteristic differences have not as yet been fully determined, but he believes such differences exist.

In his "Massige Gesteine," on page 1159, Rosenbusch takes the impregnable position that he would not consider himself justified in assigning a given rock to trachydolerite or basalt proper when the evidence of the rock itself does not suffice to indicate such assignment. But in the "Elemente," on page 402, he lays down certain rules (Regeln) which may be used in assigning a basaltic rock to trachydolerite. These rules are cited here to serve as the best available basis for judging whether the Hawaiian basalts may be referred to the Alkalic or calc-alkalic series in the sense of Rosenbusch.

The rules are briefly as follows: (1) The presence of even the smallest amount of nephelite, leucite, sodalite, or other lenad or of alkali-pyroxene or alkali-amphibole shows the rock to be a trachydolerite. (2) More than 5 per cent of combined alkalies, especially with high potash, does not speak for true basaltic character. (3) Geologic association with alkali trachyte, phonolite, or other alkali rocks speaks for the trachydoleritic nature, and association with trachyte, andesite, dacite, etc., for the true basaltic character.

The third rule clearly violates the principles set up by Rosenbusch for his own guidance, as above quoted, and is manifestly illogical and misleading so long as there is any question of fact as to whether clearly marked alkalic and calcic types occur together. The second rule is certainly vague enough and has no practical application to Hawaiian basalts, in many of which the combined alkalies exceed 5 per cent, though in most they are much less than 5 per cent.

The first rule is an exaggerated statement based on facts in the association of many rocks. As to nephelite and leucite, particularly, its universal applicability may be questioned. It seems to me that nephelite has long been given a systematic importance in the qualitative systems of classification far beyond its merits. Its presence in moderate amount is not so much an indication of highly sodic or alkalic character of a magma as of relatively low silica. Like olivine, nephelite and leucite are dependent for their development on physical conditions as well as chemical relations.

Rosenbusch [2] remarks as to olivine: "The absence or presence of olivine is not a consequence of the chemical composition of the magma but of the conditions of crystallization and specially of the more rapid or slower consolidation and the corresponding shortened or lengthened period of resorption." As has been repeatedly pointed out in this paper, an abnormative development of olivine must free silica, which becomes available to increase the silicity of other molecules, and may prevent the formation of small amounts of nephelite. There may be conditions which increase the amount of nephelite.

Probably all petrographers recognize that there are recurrent peculiarities in the rocks of different regions which are apparently derived from similar parent magmas. Iddings, Brögger, Lacroix, Washington, and many other students of notable areas have made this conclusion incontestable. Rosenbusch has made it the basis of systematic classification. But has he not gone much too far in the sharp distinction of the Alkalic and Calcic series and the generalization, to which he gives all the force of an established law, that the members of the two series do not and may not occur together as differentiation products of one magma? Is there not a mass of evidence to prove that types of the two assumed series do mingle in many petrographic provinces or centers of eruption, as differentiates from the same parent magma? Before such a general law can be accepted as a basis for systematic classification is it not incumbent on petrographers to demand at least a reasonable hypothesis to explain why two similarly constituted magmas, one an andesite and the other a trachyandesite, or one a basalt and the other a trachy-

[1] Mikroskopische Physiographie der massigen Gesteine, 4th ed., p. 1159, 1908.
[2] Elemente der Gesteinslehre, 3d ed., p. 395, Stuttgart, 1910.

dolerite, may not on differentiation produce many similar and even identical types? If such overlap is impossible, why is it not also true of the derivatives from two basaltic or two trachydoleritic parent magmas, which may well differ from each other in composition more than many pairs of rocks whose analyses are quoted by Rosenbusch, one of trachydolerite and the other of basalt?

The facts presented concerning the Hawaiian lavas and their relations seem to furnish significant data, bearing on these questions, which will be discussed in the next section.

Distinction between Alkalic and Calcic series.—The chemical characters of Hawaiian lavas and the circumstances of their association demonstrate that so-called alkalic and calcic magmas may and do occur together as derivatives from a common source. This evidence is supported by the facts of many other eruptive centers, some of which will be cited. The current generalization—always largely assumption—that this distinction between the Alkalic and Calcic series is of fundamental importance in petrogenesis and may serve as a factor in a natural system is, in my opinion, absolutely false and is leading to needless confusion in various problems of igneous rocks.

Much of the world-wide evidence bearing on this question is not readily put in convincing form. The table of analogues of Hawaiian lavas presents many suggestions for further investigation, when the new edition of Washington's Tables is available. A general review of the subject has led Iddings[1] to express his belief that the distinction under discussion is not in accordance with the facts of nature.

Studies of Tahiti and Reunion have led Lacroix[2] to the clearly expressed conclusion that in those islands alkalic and calcic magmas are comagmatic associates. Weber's studies of Samoan lavas resulted in the same conclusion for that island group, in spite of an evident predisposition to accept the Rosenbusch generalization. Weber[3] mentions several places, in different countries, where alkalic and calcic rocks occur together, and raises the question whether the idea as to the separation of the series has not been carried too far. Washington has shown in a recent study of rocks from Sardinia that alkalic and calcic rocks are there associated as derivatives from the same magma, and he expresses the opinion that the Rosenbusch generalizations are incorrect. Many other writers have pointed out instances where rocks of the two series are associated, but in many such instances it has not been clear that the rocks were of the same period of eruption and were genetically associated.

DIFFERENTIATION OF HAWAIIAN MAGMAS.

The general problem.—It appears to be impossible to escape from the conclusion that the series of Hawaiian lavas have been derived from a general magma of nearly the same character in all parts of the province. The origin of this provincial magma is a still broader problem, beyond the scope of this discussion. The process or processes involved in this secondary differentiation are perhaps no more clearly indicated by definite evidence here than in other regions, and I confess to the feeling that all current hypotheses fail to render satisfactory explanation of all the phenomena or relations observed. And in the present state of knowledge (or of ignorance) concerning the processes of differentiation, it is reasonable, I think, to believe that there may be forces operating on magmatic solutions in the chambers or conduits of the earth's crust, the potency of which to produce the observed results has not been appreciated, or even that there may be forces of which we are now ignorant.

Speculation and the formulation of hypotheses and theories on this subject are highly desirable and may be of great value, but it is only necessary to review the recent literature of magmatic differentiation to make it clear that there is no adequate basis of physical and chemical facts pertaining to this question from which speculation and hypothesis must start. The fact that Daly has recently published a paper on the differentiation of Hawaiian magmas gives a natural trend to the brief discussion which follows.

[1] Igneous rocks, pt. 2, p. 464, New York, 1913.
[2] Soc. géol. France Bull., 4th ser., vol. 10, pp. 91–124, 1910; Compt. Rend., vol. 155, pp. 538–544, 1913.
[3] K. bayer. Akad. Wiss. math.-phys. Klasse Abh., vol. 24, pt. 2, p. 305, 1909.

The first essential is, as Daly remarks, to establish the approximate character of the parent magma, as nearly as may be, to review the composition of the known products of differentiation, and then to consider the processes involved.

The provincial magma.—The composition of the parent magma of the Hawaiian province can not be closely determined, of course, but the average composition of rocks analyzed seems likely to be nearly representative of the general Hawaiian magma. A large number of the Hawaiian analyses are of the basaltic types, so that the rare and more or less imperfectly complementary extremes have less effect on the average than is commonly the case when similar averages have been calculated, with fewer analyses.

In the subjoined table the column marked α represents the average of the 43 analyses of the table on pages 47–48, β is the average of 29 analyses of lavas of the island of Hawaii, γ is the average of 9 analyses of lavas of Halemaumau, of the "C.-O.-A. group" discussed on page 60; δ is the average of 198 analyses of basalt, calculated by Daly [1] to represent the world basalt; ϵ is the analysis of the dolerite of Londorf in Hesse, quoted by Rosenbusch [2] as a type of true or calcic basalt. The norms corresponding to the averages and the Londorf rock are also given.

Average analyses and norms of lavas.

Analyses.						Norms.					
	α	β	γ	δ	ϵ		α	β	γ	δ	ϵ
SiO_2	48.69	50.12	50.18	49.06	49.08	Orthoclase	7.23	7.78	4.45	8.90	6.1
Al_2O_3	14.00	14.32	14.12	15.70	13.43	Albite	29.87	27.77	22.53	26.20	28.8
Fe_2O_3	5.03	4.61	3.04	5.38	6.49	Anorthite	18.63	20.29	24.19	24.46	18.3
FeO	8.01	8.52	10.45	6.37	5.92	Diopside	18.57	17.89	22.42	13.60	17.6
MgO	7.12	6.23	6.42	6.17	9.58	Hypersthene	3.46	11.42	17.02	12.07	8.3
CaO	9.00	8.82	10.67	8.95	8.92	Olivine	9.33	4.18	1.48	1.70	7.0
Na_2O	3.55	3.31	2.69	3.11	3.42	Magnetite	7.19	6.73	4.41	7.89	9.3
K_2O	1.24	1.25	.75	1.52	1.00	Ilmenite	4.41	2.58	3.34	2.58	3.5
TiO_2	2.29	1.37	1.75	1.36	1.82	Apatite	1.16	.52	.51	1.07	1.3
P_2O_5	.49	.22	.21	.45	.51						
MnO	.41	.43	.19	.31	.....		99.85	99.16	100.35	98.47	100.2
	99.83	99.20	100.47	98.38	100.17						

Rocks of the composition of the averages α and β and the dolerite of Londorf fall in subrang camptonose (III.5.3.4) and are not transitional in any respect. The Londorf rock corresponds to the general average α in its normative composition more closely than any other basalt of which I have found an analysis. The "C.-O.-A." average of Halemaumau (γ) falls in subrang auvergnose (III.5.4.4–5) through its lower soda but is transitional to camptonose. The world basalt of Daly (δ) is more salic than the Hawaiian averages, in consequence of its higher alumina, and is andose-camptonose ((II)III.5.3.4).

The data at hand seem to require that a discussion of differentiation in the Hawaiian province should assume the parent magma to have had nearly the composition of the concordant averages α and β, and that lavas of widely variant composition have been derived from that magma by differentiation, directly or indirectly.

The differentiates.—Whatever the parent magma may have been, the nature of the differentiation that has taken place is represented, though doubtless imperfectly, by the rock analyses which have been cited. An examination of the analyses and of the table of normative ratios (opposite p. 56) will show the important phases of this differentiation in many details. A summary of the leading features of variation from the mean of the 43 analyses (α) may be of interest at this place.

With regard to the relation $\frac{\text{Sal}}{\text{Fem}}$, 21 rocks are more salic and 22 more femic than the mean. At the salic extreme are three rocks separated by a large gap from the next most salic type (No. 4), while there is a more continuous gradation through the more femic part of the series.

[1] Jour. Geology, vol. 19, p. 305, 1911.

[2] Elemente der Gesteinslehre, p. 399, 1910.

The variation in silica in these rocks has some interesting features. Only three rocks are notably higher in SiO_2 than the mean, and five are somewhat poorer in it. For 34 rocks the variation in SiO_2 is but 3 per cent on either side of the mean of 48.69, yet these rocks range in the quantitative system from near the middle of Class II well into Class IV, showing how relatively unimportant the variations in SiO_2 may be compared with those of the bases. Two of the most femic rocks have only about 2 per cent less SiO_2 than the mean.

In these rocks SiO_2 does not vary in accord with any other particular constituent. While the most alkalic are also the most siliceous rocks, Nos. 3 and 4 have the same contents in Na_2O, nearly equal combined alkalies, and about 10 per cent difference in SiO_2.

The variation in alumina is much more important than that in silica, both quantitatively and for its influence on the mineral composition. While in many of the rocks Al_2O_3 varies with Na_2O or the combined alkalies, in some high Al_2O_3 goes with low alkalies, causing a great increase in normative anorthite, as in Nos. 8, 9, 11, 17, and 22. Among the more femic rocks the relations of Al_2O_3, SiO_2, and alkalies are also extremely variable. Thus in Nos. 33 and 37, each with 12.10 per cent Al_2O_3, the SiO_2 is high and alkalies low in the former and the reverse in the latter rock.

Lime is also independent of other oxides in its variations. Rocks carrying less CaO than the mean are scattered through the list from No. 1 to No. 42, the SiO_2 ranging in these same rocks from 62.19 to 36.85 per cent. No. 36 has the same CaO as the mean, with 12 per cent less of SiO_2, and No. 28 has the same CaO with 3 per cent more SiO_2 than the mean, so that there is a range of 15 per cent in SiO_2 with the same CaO contents.

The alkalies range from 1.61 per cent (No. 42) to 13.31 per cent (No. 2), and while the most salic rocks are highest in alkalies there is no regular variation, as a glance at the table will show. Soda is much more abundant than potash and there is a tendency for the two to vary in accord, though some exceptions are notable.

The most variable constituent oxide of the Hawaiian magmas is magnesia. It ranges from 0.16 to 21.79 per cent and goes even higher in the peridotitic xenoliths. There is a general increase in magnesia with increase in femic molecules of the norm. This is natural, for MgO is only found in femic silicates.

The determinations of the iron oxides are open to so much question as to their accuracy that it is best to consider the variation in the total iron contents of the rocks. While it would be more accurate to calculate all the iron to FeO, this is unnecessary for the general purpose of the present discussion, for it is manifest that iron is not distributed in the same manner as magnesia, in spite of the fact that its normative compounds are all in the femic group. A glance at the table of analyses, which are arranged on the ratio of $\frac{Sal}{Fem}$, will show that the amount of iron is most strikingly independent of the abundance of femic molecules. In No. 4, with 37.6 per cent of Fem, there is 10.54 per cent of iron oxides, while in No. 42, with 72.7 per cent of Fem, the iron oxides form but 12.66 per cent. Rocks numbered 12, 13, 15, and 16, all of which belong to the transition zone between Classes II and III, are richer in iron than any four rocks of Class IV, or, indeed, than any of the entire 27 rocks richer in femic molecules. Among the rocks more femic than the average (α) only four are richer in iron, while seven more salic rocks have higher iron contents. The variations of all other principal constituents are greater than those of iron.

It has been pointed out that Silvestri's analyses are apparently too high in iron oxides, but the general statement in regard to the variation in iron is true, even if all Silvestri's analyses are disregarded.

Titanic oxide shows no special tendency to concentration, being distributed quite independent of the ratio $\frac{Sal}{Fem}$.

Processes of differentiation.—The results of differentiation in Hawaii are known only as effusions, with a few dikes near the surface. No large intrusion, no stock or conduit has been found. The differences in composition shown by the lavas are such as may originate in the space

belonging to the volcano, in its conduit, or in the chamber or reservoir for its magma. Assimilation of foreign material can not be plausibly assumed to have modified the magma, as it is supposed to have done in many other igneous centers.

Daly [1] has approached the problem from practically the same standpoint and explains the formation of the more mafic and felsic lavas by certain definite processes. Gravitative adjustment within the conduit is thought ample to explain the ultrafemic and some of the salic lavas, while the assimilation of coral limestone has indirectly led to the formation of the rare trachyte, in accordance with the hypothesis formulated by him a few years ago.[2]

Let us see how far the facts contribute support to Daly's hypotheses.

Gravitative differentiation.—It is not difficult to conceive of a kind of differentiation due to gravitative adjustment in a body of magma containing heavy crystals of olivine, pyroxene, magnetite, etc., in a still liquid, lighter, salic residue—given sufficient time. But apparently this process is more readily conceived in the study than carried out in nature; for, while there are a goodly number of intrusive sills and laccoliths where a concentration of the heavier constituents in the lower zones has been plausibly attributed to this process, such concentration is conspicuously absent in a vastly larger number of apparently similar occurrences. I have not found any such case in many seasons' experience in the examination of intrusive bodies.

Daly explains the more mafic lavas as due to the sinking of heavy silicates by gravity to low levels in the volcanic conduit, where they are resorbed and gradually change the character of the dissolving magma. At the same time the magma of the upper part of the conduit becomes more salic. After extensive changes of this kind an eruption from the upper portion of the conduit would produce andesitic or similar lavas, while if the deeper parts of the lava column were tapped highly femic magmas, such as the Mauna Loa flow of 1852, would come to light. He says [3] that "no fact in the field relations opposes the assumption of a very deep, direct source for these heavy magmas."

The facts that the 1852 flow issued from Mauna Loa 1,300 meters below its summit and that the porphyritic gabbro of Kilauea occurs 3,000 meters below the same level are cited in favor of the assumption. To these data may be added the occurrence of the olivine-rich basalt of Puna at sea level and of the picritic basalt of Haleakala at its summit. This range of level for the four heaviest known lavas of Hawaii and Maui scarcely supports any generalization as to a relation between the specific gravity of a lava and the level of its issue.

The complementary proposition, that lighter lavas are apt to occur at higher levels, is thought by Daly [4] to be illustrated in Mauna Kea. This mountain is described as practically stratified, in that it is supposed to consist of olivine basalt below 6,000 feet and generally lighter rocks above that level to the summit, where the lightest rock, trachydolerite (No. 5), occurs. Here, again, Daly's data are, I think, obviously inadequate to serve as the basis for such a conclusion. His observations appear to have been limited to a traverse from the saddle on the south, at about 6,000 feet, to the summit and back, the usual route of approach. The constitution of this great volcano is still almost unknown by direct study of its lavas.

But even if lavas lighter than normal basalt descend on all sides of Mauna Kea to about 6,000 feet, they must be considered as simply a veneer of the later eruptives and give no evidence of the character of underlying lavas, which must have descended likewise from vents above. Moreover, the collection studied by Cohen [5] and that made by Preston [6] showed the presence of heavier basalts on the upper slopes of Mauna Kea, though their distribution and occurrence are unknown.

The occurrence of very mafic and felsic lavas together at the summit of Haleakala has been described (pp. 28–30). Trachytic rocks occur at low levels on both Hawaii and Maui, and on reviewing the data of occurrence at my disposal I can see no sufficient basis for the generaliza-

[1] Jour. Geology, vol. 19, pp. 289–316, 1911.
[2] Geol. Soc. America Bull., vol. 21, pp. 87–118, 1910.
[3] Op. cit., p. 306.
[4] Idem, p. 310.
[5] Neues Jahrb., 1880, vol. 2, pp. 23–62.
[6] U. S. Coast and Geodetic Survey Ann. Rept., 1893, pt. 2, appendix 12.

tion that on Mauna Kea or in the Hawaiian Island group the more basic (that is, heavier) lavas have issued more frequently from lower levels while the lighter ones characterize the upper slopes of the volcanoes.

Mauna Kea is the only one of the great volcanoes of Hawaii in which the occurrence of the lighter lavas near the summit is supposed by Daly to be in accord with the gravitative hypothesis. At the other centers the conditions are recognized as having been unfavorable to gravitative differentiation, mainly on account of the energetic "two-phase connection," a process resulting in the vesiculation of the magma at considerable depth.[1]

Origin of trachyte and melilite basalt.—Daly considers that the soda trachyte of Puu Waawaa and the nephelite-melilite basalts may have resulted from the absorption of coral or foraminiferal limestones, "such as are known to be interbedded with the older lavas of the archipelago,"[2] and according to the process formulated by him to explain the alkalic rocks in general.[3] The occurrence of soda trachyte and nephelite-melilite basalt in proximity on Maui would presumably be considered by him as favoring such an explanation.

With regard to this hypothesis I can see no reason for supposing that the rocks mentioned are not, in Hawaii and elsewhere, products of the same general process of differentiation as the other rocks with which they are associated. They are simply the extreme phases of the group now known and are connected by intermediate lavas with rocks assumed by Daly to result from gravitative differentiation. To be sure, the trachytes do not occur at the summits of volcanoes, but that does not form a valid reason for excluding them from the category of phenomena having a bearing on the gravitative hypothesis.

I am not aware of any basis for the broad statement that limestones are generally associated with the older lavas of the archipelago, nor indeed that they occur in such association at any point. Coral rock is known on the south shore of Oahu at considerable depths and to some extent alternating with lavas and ash beds, but that these belong to the old lavas of the principal centers rather than to later eruptions is not demonstrated and is, indeed, questionable. The limestones occur in what Hitchcock[4] calls the Pearl Harbor series, which Dall considers to be of late Tertiary age. The sweeping conclusion drawn by Hitchcock,[5] on the basis of the character of this series, that "there is ground for the belief that the foundation of the whole archipelago is a Tertiary limestone traversed by eruptives," needs some statement of that ground.

Granting that there may be superficial deposits of coral limestone about some of these islands, it is necessary, for Daly's hypothesis, to show how such material can gain access to the volcanic conduit in mass sufficient to produce any notable result. It is certainly true that the alkali-rich lavas are not present about Honolulu, where the limestone deposits are best known. By Daly's hypothesis for the alkalic rocks the felsic lava should be at the upper levels and the mafic below. If this arrangement existed at the time of the numerous subsidiary eruptions about Honolulu, it seems remarkable that no alkalic magma came to eruption.

The importance attached to the association of limestones and alkali rocks emphasized by extensive tables in Daly's original paper presenting his hypothesis[6] appears to me quite unwarranted. If an alkali rock cuts a limestone in dikes or stocks, this fact proves that that limestone did not have anything to do with the alkalic character of the crosscutting body. The fortuitous association of limestone and alkali rocks in many parts of the world is natural enough, but that it has any significance for this problem remains to be shown. The few known cases where magmas have been injected into limestones under conditions causing assimilation and reactions leading to important modifications of the magma appear to be of local importance only. The interesting hypothesis recently advanced by Smyth[7] that magmatic mineralizers have had an important part in the concentration of the alkalies and of other rare elements often found in pegmatites, deserves careful consideration. The general conclusion of Smyth that alkalic rocks are simply special derivatives from a "subalkalic" magma agrees entirely with my own views.

[1] Jour. Geology, vol. 19, p. 311, 1911.
[2] Idem, p. 309.
[3] Geol. Soc. America Bull., vol. 21, pp. 87–118, 1910.
[4] Idem, vol. 11, p. 32, 1900.
[5] Idem, p. 33.
[6] Geol. Soc. America Bull., vol. 21, pp. 92–109, 1910.
[7] Am. Jour. Sci., 4th ser., vol. 36, pp. 33–46, 1913.

Differentiation and the sequence of lavas.—The exhaustive descriptions of Kilauea given by Dana, Hitchcock, and Brigham, together with comparatively meager observations of less accessible centers, have made that the accepted type of basaltic volcano of the world. Nevertheless this type is usually described in terms suggested by observations bearing on only a part of the history of such a volcano. That this is true will be appreciated by any geologist seeking to compare the sequence of chemically different lavas in relation to the life history of the volcano.

The early periods of each center are actually unknown, either as to their physical phenomena or as to the character of the lavas. There has been no attempt to examine, except in a casual way, the eroded core of any Hawaiian volcano. It has been tacitly assumed that the early lavas of all were basalts comparable to those of Kilauea. Perhaps they were, but it is certainly desirable to ascertain the facts at the most deeply dissected centers of Kauai, Oahu, and the remnants of large volcanoes presented by some of the smaller islands.

While the older history is difficult to unravel, there is a later period which has received very slight attention, except from its physical side, although the data for its study are very abundant on all the larger islands. This period began at about the time when the great low-arched shield of the volcano was complete and eruptions of the common types had ceased. But apparently volcanism was by no means fully extinct at this time, and it came again and again to eruptive manifestation during the long epoch of dissection and destruction of the volcanic pile.

While my own observations are quite insufficient to permit an adequate sketch of the phenomena of this later period, the problem of differentiation in Hawaii is so bound up with its history that I wish to outline what seems to me the general character of the epoch of decadence in volcanic activity and its relation to the chemical composition of the recent lavas.

Mauna Loa and Mauna Kea are twin giants of the same general size and low dome or shield outline. The former is still active and the latter is referred to as extinct. A striking difference between them is found in the great number of cones of ash and cinders, with or without local flows, which are scattered over the surface of Kea and are rare or lacking on Loa. Whether such subsidiary eruptions occurred in the earlier history of these volcanoes or not, they were certainly more abundant in and characteristic of the decadent period. There are cones and local flows in Puna, adjacent to Kilauea, which seem plausibly related to that center.

These small eruptions were not confined to the time immediately after the cessation of the normal type of basaltic eruption, by which the mountains had been built up, but were repeated at intervals long after the mountains had been dissected even to the point where it becomes difficult to locate the old center of eruption.

Apparently these subsidiary outbreaks were at first most numerous on the upper slopes of a volcano, as indicated by their distribution on Mauna Kea and Hualalai, but as the main conduit became more and more effectively clogged the spasmodic outbreaks occurred more frequently on the lower slopes. In West Maui, Oahu, and Kauai many of the more recent ash eruptions have occurred at or near sea level. On Oahu and Kauai ash and cinder deposits occur at various altitudes on ridges and in canyons or on precipitous slopes, and I have the impression that some of these deposits were not derived from visible centers of lower level.

The relation of this subsidiary volcanism to magmatic differentiation appears in the fact that the more salic and femic lava types are as a rule products of these recent and local eruptions. I am not in a position to assert either that they are restricted to such outbursts or that all lavas of these eruptions are of highly differentiated character. But that such is the general rule is well established.

As I look at it, the relations of magmatic differentiation, as suggested by the sequence of lavas, to the history of Hawaiian volcanoes corresponds approximately to the following outline. If we assume that the initial magma at each center of eruption was of a basaltic character, similar to the average α of the table on page 87, it seems that during the more active period of each volcano differentiation was seldom if ever able to produce partial magmas of extremely salic or femic character. This might be due to short periods of quiet in the magma chamber or reservoir, insufficient to produce great differentiation. Even between eruptive periods there

might be internal movements of the magma, accompanying changes of temperature, sufficient to again mingle parts of somewhat different composition. At any rate the lavas of extreme composition are not known in the main mass of any volcano.

The "ultrafemic basalt" of 1852, from Mauna Loa, and possibly some other similar lavas may be exceptions to this generalization. But it is also possible that such lavas indicate a slowing of the activity at any center and the beginning of a period in which differentiation is able to produce more femic or more salic magmas than before. Further investigation is necessary to determine how early in the sequence of lavas at a given volcano such femic magmas may appear.

No very salic lavas have been found on Mauna Loa or Kilauea. The interesting rocks belonging to andose, found on the upper slopes of Mauna Kea by Daly, are probably products of subsidiary eruptions. Daly states that the "trachydolerite" of which he submits an analysis (No. 5) issued from a cinder cone near the summit. All the flows of this rock are said to be short and some were seen to be connected with cinder cones. The similar "andesitic basalt" (No. 7) is not reported by Daly to have such evident connection with these recent and local eruptions, but there are reasons, presented in another place (p. 89), for objecting to the view of Daly that all the upper 6,000 feet of Mauna Kea is composed of these salic lavas. It seems to me that they can be only a veneer—and probably not continuous, at that—over the basaltic summit of the mountains.

Very little is known concerning the constitution of the old volcanic center represented by the mountains of the Kohala district, forming the northern peninsula of the island of Hawaii. Dutton's general statement that the lavas are, as a rule, more nearly andesitic than basaltic[1] must be questioned in view of the occurrence of normal basalts (of unknown localities) described by Cohen.[2] The highly salic kohalaite and another rock analyzed by Lyons (Nos. 3 and 10) came from the southern slope of the mountain near Waimea, and as the map of Hawaii shows subsidiary cones to be abundant on that slope, as well as scattered over other parts of the peninsula, it is not unreasonable to assume that the salic lavas came from the late eruptions of the Kohala center and that the main mass may be of common basaltic rocks.

The genetic relations of the soda trachyte of Puu Waawaa and the Anahulu terrace (p. 35) are as yet questionable. Puu Waawaa seems to belong among the subsidiary cones of Mount Hualalai but is older than some of its basaltic lavas. The similarity between this trachyte and that near Lahaina, on Maui, suggests a very late date for the former in the history of the center to which it belongs. The query then arises, May the trachyte of Puu Waawaa be in fact an outlying eruption belonging to the Kohala center, which by chance comes in proximity to Hualalai? Further observations are necessary on this point.

The salic lavas of Haleakala, on Maui, of which two analyses have been given (Nos. 4 and 6), are, with the accompanying picritic basalt (No. 39), products of the most recent eruptions of the crater of that volcano. (See p. 30.) Apparently these are the only rock types of Haleakala that have been studied, and there is no distinct evidence of the rôles they play in the constitution of that great volcano. My own view of the relations at the summit of Haleakala rests on meager observations and may be quite incorrect, but I give it, with some hesitation, chiefly as a suggestion to future students of that grand volcano.

What is commonly called the crater of Haleakala appears to me to be, in some part at least, a result of erosion. This great crater is about 7 miles long by 2 miles wide. At the east end, opening to the south, is the Kaupo Gap, 1 mile wide, and at the west end, opening to the north, is the Koolau Gap, 3 miles wide. The Koolau Gap connects directly with the deep canyon-like Keanoe Valley, which extends 8 or 9 miles to the sea. There is no canyon south of the Kaupo Gap because it has been filled by great flows of trachyandesite extending from the crater to the sea. The Government map represents flows as extending for more than 2 miles from the Koolau Gap down the Keanoe Valley. East of the borders of the flow through the Kaupo Gap are canyons which do not head so far back as the crater but whose beds are deeper than the surface of the flow. These canyons and many others shown by the map indicate the character of the

[1] U. S. Geol. Survey Fourth Ann. Rept., p. 171, 1884.

[2] Neues Jahrb., 1880, vol. 2, p. 47.

gorge which once penetrated through the Kaupo Gap into the summit crater. How much of the crater is erosional remains to be determined.

The absence of any data as to the character of the rocks of the crater or canyon walls makes it uncertain at the present time whether the trachyandesite and picritic basalt had a part in the constitution of the volcano before the gaps were made or not. J. D. Dana says that the walls of the crater are made up of rock similar to that of the cone called White Hill—trachyandesite—but no specimens were collected, and this statement needs confirmation. Dana's collection from Maui contains two specimens of trachyandesite, said to occur near Paia, on the coast at the north base of the mass of Haleakala. It is not known whether these specimens represent lavas of the main mountain complex or local eruptions. A cone occurs near Paia.

Until evidence to the contrary has been procured it seems most natural to assume that Haleakala is, like other Hawaiian volcanoes, essentially basaltic, and that the extreme salic and femic rocks known from its crater belong to subsidiary eruptions, later than most of the canyon erosion to which the mass has been subjected.

There are numerous cinder cones on the slopes of Haleakala, but the nature of their lavas has not been determined.

West Maui presents another great volcanic pile of which little is known. On its slopes are many cinder cones with small flows. At one of these, near Lahaina, on the west coast, occurs the soda trachyte (No. 1) first mentioned by Dana and identified also by Möhle, who found it, together with melilite basalt; among the specimens collected by Schauinsland in the same vicinity. This occurrence seems to connect the most felsic with one of the most contrasting or complementary mafic types, as genetically closely related.

About Honolulu, Pearl Harbor, and many other low-lying parts of Oahu are numerous cinder cones, and, as has been shown (pp. 20–24), the ashes and lavas from them are usually of very basic character, including nephelite-melilite basalt, nephelite basalt, limburgite, and other unusual types. No felsic rocks are known from these vents, but the association of extreme felsic and mafic types near Lahaina confirms the reasonable idea that complementary felsic magmas probably exist in depths at Oahu but have not come to eruption. The perfect forms of Punch Bowl, Diamond Head, and other cones or crater hills of unconsolidated materials show how recent they are, and there is no reason to be confident that further eruptions may not occur on the island of Oahu.

On Kauai conditions are similar to those on Oahu. The most mafic lava of the island is the nephelite-melilite basalt of Kilauea Bay (No. 43), on the north shore, which is of local origin. Cones, with or without craters, are scattered over the island, less abundantly than on Oahu, but the character of the materials erupted in most of them has not been determined.

General course of differentiation.—From the preceding data concerning the differentiates of the Hawaiian primary magma and their time relations to the activity at various centers some tentative conclusions may be drawn.

1. It does not seem probable that there has been any noteworthy differentiation in the main reservoir beneath the Hawaiian district. It being supposed that some volcanoes are much younger than others, the recent ones appear to have presented the same variety of basaltic types during their main activity.

2. During the active growth of each volcano the lavas presented a moderate variability in composition without detected system of variation. The processes of differentiation were too frequently interrupted to permit strongly pronounced results.

3. With decreasing eruptive activity and possibly attendant contraction and limitation of lava chambers, a higher degree of differentiation was accomplished and is shown by more salic and correspondingly more femic lavas than those of earlier date.

4. In the long period of parasitic or subsidiary eruptions conditions were favorable to extensive differentiation. This may be due to a localization of smaller magmatic chambers or to lengthened intervals of quiet.

5. The processes of this differentiation are still problems for investigation. To me they appear to have acted mainly upon the liquid magma. Movement, under gravity, of crystal particles may have played a part.

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